III.—*On the Physical Conditions involved in the Construction of Artillery, and on some hitherto unexplained Causes of the Destruction of Cannon in Service.* *By* ROBERT MALLET, *Mem. Ins. Civ. Eng., F. R. S.*

Read June 25th, 1855.

1.—*Introductory.*

1. THAT marvellous substance, gunpowder, whose discovery (in Europe at least) we trace to the cell of Roger Bacon, at Oxford, seems within little more than sixty years, to have become known and applied, as an engine of warfare throughout Europe and the East.

So stimulated was the invention, even of those torpid times, by the surprising nature of the new power conferred, that, but a few years sufficed to bring cannon to a *size* at least, that has never been surpassed in modern days, as, for example, in the gun of bronze, cast for Sultan Mahomed for the siege of Constantinople, in 1453, of eleven palms in caliber; some of the "confreres" of which still guard the Dardanelles, and a stone shot from one of which nearly destroyed a frigate of Admiral Duckworth's squadron in 1806.* (Note A.)

For nearly three hundred years, cannon of great caliber, many of which were made of separate staves and hoops of wrought iron, continued the favourite of artillerists throughout Europe; so that in Queen Elizabeth's and even in Cromwell's time, both here and on the continent, field guns were in use, of a magnitude now scarcely known except as guns of position.

The opinion, however, that guns of less caliber, in greater number, and served more rapidly, were more efficient weapons, gained ground; and at the

* De Tott, Travels, &c.

beginning of last century the caliber of cannon for both land and sea service was reduced, perhaps, much below the middle point of prudence.

The paper of Mr. Robins, published in 1746, entitled "A Proposal for new Arming the British Navy, by boring out all the eighteen pounders to guns of larger caliber," was perhaps the first step towards that return to artillery of the largest caliber, which characterizes our own day. The progress of these views, the constant consolidation in construction of fortified places, and improvements in the strength of ships of war, have all tended to increase the size of modern artillery, resulting, amongst other improvements, in the Paixhan and Lancaster guns, the use of hollow shot, &c. (Note B.)

2. During the ages occupied by these mutations, gunpowder itself has—through the greater purity of its constituents, greater skill in proportioning and combining them, and improved methods of preserving and of firing—been greatly increased in power; and hence our modern artillery of enlarged caliber is frequently subjected to a strain in service greatly exceeding anything to which the ancient enormous cannon were exposed, throwing stone shot of light specific gravity compared with iron balls: and which the confessedly great improvements in the manipulation of metals in recent times have as yet scarcely been able fully to cope with. (Note C.)

3. In considering the strains to which a gun is exposed when discharged, and limiting our views to the mere *pressure* upon its interior, produced by the elastic gases of the inflamed powder, it is obvious from consideration of the formula giving the relation between this pressure and the resistance of the cylinder of the gun,

$$p \, . \, D'' = R \, (D' - D'') = 2Re. \tag{1}$$

In which,

> p = the pressure per square inch on the interior of the cylinder;
> D' and D'' = the external and internal diameters respectively;
> R = the coefficient of cohesion of the substance of the gun;
> and e = the thickness of the gun.

That the value of p, the pressure per square inch, at its maximum point (wherever that may be, between the first instant of ignition, and the balls leav-

ing the mouth of the gun) is the element upon which alone the chief practical difficulty of increasing the caliber of cannon depends. (Note D.)

4. Now this increases enormously with every increment of caliber. For supposing the shot spherical in all cases, its weight increases as D''^3, and as the "work done" by the powder in giving it its final velocity is proportionate to,

$$\frac{1}{2}\,\frac{s\,D''^3}{g}\,V^2, \tag{2}$$

s being the specific gravity of the shot, and the length of very large guns not being very much more than those of the smaller ones in use, so that the space through which the force acts is much the same, it follows, that the maximum strain per square inch is greatly augmented. Add to this, that the lineal windage being the same, the proportionate loss of effort by windage will be less in the larger gun in about the inverse ratio of the square of the windage, and finally, when, as is often now the case, cylindrical or cylindro-conoidal shot are substituted for spherical, and so the ratio of the weight to the bore of the gun further increased, while the windage is again lessened by the contraction of the passage of escape due to the elongated form of shot; all these circumstances so increase the pressure per square inch, that the utmost resources of metallurgic skill are barely able to cope with it. And, besides the above, there are other causes of increased strain upon the gun; thus the charge of powder must be augmented largely, but its mass increases much more rapidly than the internal surface of the cylinder of the gun, which is recipient of the heat of the inflamed powder, and which carries off heat from its inflamed gases to the cold metal of the gun; hence the actual heat available for the expansion and increased tension of the gases is greater as the size of the gun is greater, so that the pressure due to this cause rises very considerably in large charges; in other words, a *large* mass of powder inflamed in a comparatively cold metallic receptacle will produce an effect more than proportional to that of a much smaller mass, so that the theoretic and the actual work done by different charges shall sensibly differ.

5. Thus the strain on the gun *increases faster* than D''^3. To meet all this, the thickness of the gun for any given material must be increased largely; but in

guns cast in one mass the external portions of the metal are far from bearing a proportional share of the strain. The pressure per square inch, whatever it may be, acts most powerfully upon the internal lamina of the bore, and when the pressure is very great, and the difference between D' and D'' is very great also, the limits of elastic extension are passed as respects the metal of the internal portions of the gun, and these are torn before any proportionate strain is visited on the outer portions. The strains producing inceptive rupture being of the nature of impulsive forces acting upon imperfectly elastic material, it always happens that a rent commenced, is followed (without any appreciable interval of time) by the flying to pieces of the whole gun.

6. Accidents of the most fatal character, resulting from the bursting of heavy iron guns, have been frequent of late years, especially of that class known as "shell guns," whose proportions unfit them generally for throwing solid shot: as for example, a 10-inch gun, of 10 feet 6 inches long, of 116 cwt., which burst at Shoeburyness on the 18th June, 1852, in firing a hollow shot of 110 lbs., with a charge of 16 lbs. of powder, at an elevation of 32°, killing several men; and another similar, but more fatal, accident, which occurred at Gibraltar; while others have taken place under the destructive conditions due to the confined space between decks in men-of-war.

These accidents have principally occurred to 10-inch and 8-inch guns, and to 68 and 32-pounders of iron; and in solid-shot guns, chiefly either in very rapid firing, or in firing red-hot shot.

One of the main objects at present in view is to point out some circumstances affecting the destruction by bursting of cast-iron guns under such conditions, which appear so far to have been unnoticed or misunderstood by artillerists—namely, the effects of unequal or local expansion produced by local inequality of temperature, whether arising from the heating of the gun internally by red-hot shot or by "quick firing,"—in powerfully increasing the strain, upon the metal, due to the discharge.

In the progress of the investigation leading to this result, however, I shall have occasion, incidentally, to treat of most of the important conditions of a physical character that affect the proper design and construction of artillery, of whatever magnitude, as well as to point out the chief circumstances upon which failure depends. In fulfilling my original object, therefore (if success-

ful), a treatise on the Construction of Artillery has resulted, embracing many views of not a little interest to science, and, as I believe, new to both the science and the practice of the gun-founder.

2.—*Directions of Fracture in Burst Guns.*

7. Before entering further upon the subject, however, it may be desirable to explain briefly the lines or directions of fracture assumed by all heavy cast-iron guns that are sound, when burst; and to point out some properties due to the molecular or crystalline structure of cast-iron, upon which in part such lines of fracture depend, and upon a due regard to which the strength or weakness of cast guns much depends. In doing so, I shall have occasion to notice, though too briefly for the importance of the subject, several circumstances and conditions bearing directly upon the gun-founder's art, which, so far as I know, have not hitherto been treated of in a determinate manner by any previous writer.

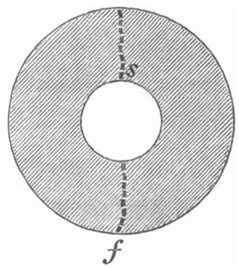
The Plate No. I. shows by the heavy dotted lines the almost invariable directions in which fracture takes place when cast-iron guns burst in proof or in service, assuming no serious flaw or other defect to exist anywhere. The gun splits up nearly into equal halves, usually by a vertical or nearly vertical plane, passing through the axis of the piece, and extending from the breech ring, which it often also divides, longitudinally to a point a little in advance of the trunnions, where it turns out to one side and to the other, leaving the muzzle portion of the gun, for a length of between $\frac{2}{5}$ and $\frac{1}{3}$ its whole length unbroken. This portion of the gun at the moment of fracture is thrown forward, partly by the direct action of the powder blast in escaping, partly through the unbalanced action of the elastic forces within the strained metal suddenly released, and partly by the friction of the passing-through shot. It usually falls to the ground with the muzzle end foremost; and as this strikes the ground the mass throws a somerset, and is found lying along, in the line in which the gun had been trained, but with the direction of the muzzle reversed, or pointing backwards; a circumstance often remarked upon with surprise by artillery officers, but, thus easily accounted for.

Sometimes the portions of the gun at, and in rear of, the trunnions are

divided by other fractures in planes more or less completely at right angles to the preceding one, and by several " turn out," or transverse fractures. These latter occur and are more numerous in proportion as the metal of the gun is harder, more highly elastic, and more rigid, and as the bursting charge is more powerful; in a word, the fragments are smaller and more numerous and irregular when the rending forces, are greatly in excess of the resisting powers of the metal. Wrought-iron and steel guns fracture much in the same way, but the fractures of bronze guns are of a somewhat different character, and the fragments are bent and distorted, both, owing to the greater toughness and ductility of the material.

8. Three circumstances are specially worthy of attention, as indicated by the lines of fracture thus generally described:—

1°. The dividing longitudinal plane, whether vertical or horizontal, is always found to assume a sudden curved form, as in diagram, at one or other side near the exterior of the gun; indicating that the *fracture begins at one side*, *s* (that opposite to the inflected fracture); and that fracture has spread from that side, the gun opening out, and the divided surfaces turning from each other upon the point of inflection at *f*.



2°. Fracture, therefore, appears in all cases to commence at the interior of the chase, and to propagate itself outwards, thus rending the metal from within to without—a result which, though difficult at first to reconcile to the imagination, is pointed to by every mathematical investigation, of the resistance of cylinders to internal fluid or elastic pressure, leading to whatever formula, since *the metal must yield first, where the pressure per square inch is greatest upon its resisting unit of section, and this is in the interior of the thickness.*

3°. *The planes of fracture follow the track, with almost unerring precision, of all re-entering angles, and of all sudden changes of scantling or dimension*, however trifling, in the external contour of the gun. Thus a vertical longitudinal fracture often passes through the vent (as being the weakest part in section), but much more frequently follows along the re-entering angle made by the exterior of the gun at its meeting with one or other side of the vent-field, as in Fig. 1 and Fig. 3. The transverse fractures,

PLATE I.

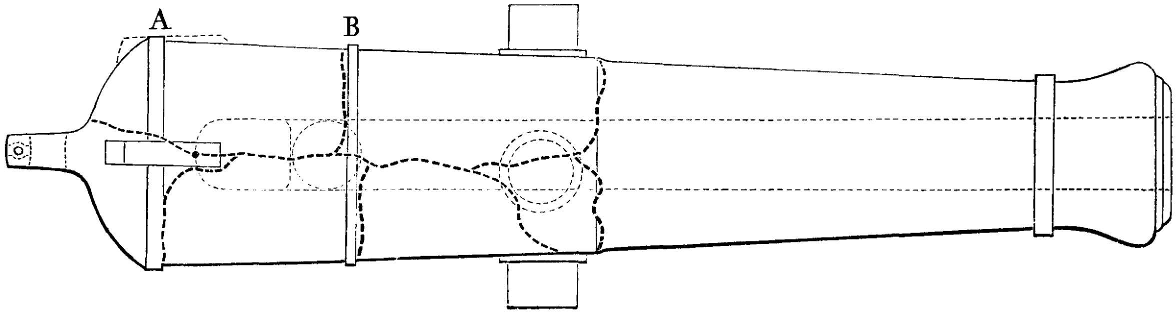


Fig. 1.

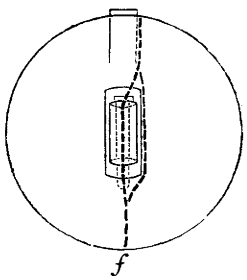


Fig. 2.

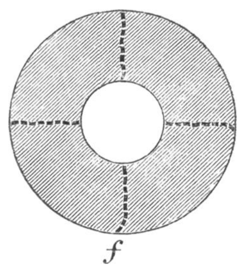


Fig. 3.

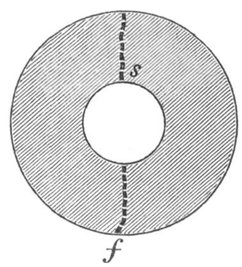


Fig. 4.

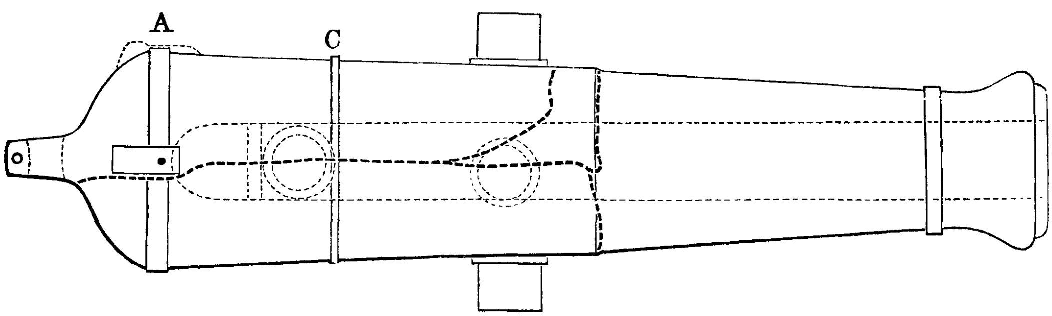


Fig. 5.

Directions of Fracture in Burst Cast-Iron Guns.

though often more or less diagonal to the axis of the gun, also mainly follow round, with remarkable regularity, the small re-entering angles made by the several breech or reinforce mouldings on the exterior of the gun; while those which approach the trunnions, usually fall into the re-entering angles made by these with the body of the piece.

No doubt these facts are familiar to every "proof master;" but I am not aware that the value of their correct observation has hitherto been recognised, or that any attempt has been made to assign a cause for them, or, in fact, to attribute the directions in which a burst gun breaks, to anything more than "accident."

3.—*Causes. Molecular Constitution of Crystalline Bodies.*

9. I proceed to explain the cause. *It is a law* (though one which I do not find noticed by writers on physics) *of the molecular aggregation of crystalline solids, that when their particles consolidate under the influence of heat in motion, their crystals arrange and group themselves with their principal axes, in lines perpendicular to the cooling or heating surfaces of the solid; that is, in the lines of direction of the heat wave in motion, which is the direction of least pressure within the mass;* and this is true whether in the case of heat *passing from* a previously fused solid in the act of cooling and crystallizing on consolidation, or of a solid not having a crystalline structure, but capable of assuming one upon its temperature being sufficiently raised, by heat applied to its external surfaces, and so *passing into* it.

10. For example,—if an ingot of sulphur, antimony, bismuth, zinc, hard white cast-iron, or other crystallizable metal or atomic alloy; or even any binary or other compound salt or haloid body, as sulphuret of antimony, calomel, sal ammoniac, various salts of barytes and lime, chloride of silver or of lead, chromate of lead; or even certain organic compounds, such as, camphor, and spermaceti,—provided only it be capable of aggregating in a crystalline form under the influence of change of temperature, as from fusion or sublimation;—if an ingot or mass of any such body be broken when cold, *the principal axes of the crystals will always be found arranged in lines perpendicular to the bounding planes of the mass; that is to say, in the lines of direction in which the wave of heat has passed outwards from the mass in the act of consolidation.*

11. But conversely, the same effect is found produced by the application of heat (far below that of fusion) to the surfaces of solids, which are capable of solidification in either of the two states, homogeneous (amorphous) or crystalline, and have solidified in the former. Of such bodies many are known; for example,—many of the metals, glass, carbon in certain states, chalk when crystallizing into marble under pressure and ignition, arsenious acid, realgar, protoxide (litharge) and iodide of lead, ice; and amongst even organic compounds, sugar, paraffine, &c.

12. If a cylinder of lead, of some four or five inches long, and about the same in diameter, be cast around a cylindrical bar of iron, of about $1\frac{1}{2}$ inches diameter and some 2 or 3 feet long, the lead, on becoming cold, and rapidly consolidated by the contact of the cold iron bar interiorly, will have a perfectly homogeneous structure; it may be cut into, beaten out, &c., without presenting any trace of crystallization.

If, however, one of the projecting extremities of the central iron bar be now placed in a furnace and heated red hot, and time be given until the heat conducted along the bar, and from it passed into the interior parts of the lead cylinder, and thence transmitted outward, radially through it in all directions, shall have raised the temperature of the lead itself to within a few degrees of its melting point—say to about 550° Fahr.—and the lead be now struck sharply with a hammer, the whole mass will be found to have assumed internally a crystalline structure, all the principal axes of the long thin crystals radiating regularly outwards from the axis of the cylinder to its surface; and by a few blows of the hammer, the whole mass will separate and fall to pieces as a metallic dust—so complete are the planes of separation of the crystals. (See Plate II. Fig. 4.)

13. A piece of cylindrical brass wire, tough, longitudinally fibrous, and presenting no trace of crystallization, may in the same way be caused to become almost instantly brittle and crystalline, if passed endways into the centre of a red-hot iron tube of small diameter (such as a gun-barrel), held vertically; the crystals all radiating from the axes of the cylinders.

14. If a flat thick plate of rolled or malleable zinc, which is nearly homogeneous in structure, or, if not so, presents fibres and lamina in the plane of the plate, be laid down flat upon a cast-iron plate, heated to within a few degrees

of the melting point of the zinc, it assumes very soon a crystalline structure,—the crystals having their principal axes now all cutting perpendicularly through the plate from side to side; in other words, *the planes of internal structure being in this and the former case absolutely turned round* 180° *of angular direction.*

15. The same change of structure takes place more strikingly in glass; when exposed for a considerable time to a heat short of fusion, or even of complete softening, it is converted into the opaque substance known as Reaumur's porcelain, in which a crystalline structure is developed, and the principal axes are arranged perpendicular to the surfaces recipient of the heat.

Many other instances might be adduced, were this the place to pursue so tempting a subject. But enough has been given to indicate the generality of the law. (Note E.)

4.—*Molecular Constitution of Cast-Iron.*

16. Now cast-iron is one of those crystallizing bodies which in consolidating obeys, more or less perfectly, according to the conditions, this law also; so that generally it may be enunciated as a fact that *in castings of iron the planes of crystallization group themselves perpendicularly to the surfaces of external contour*, that is to say, in the directions in which the heat of the fluid cast-iron has passed outwards from the body in cooling and solidifying.

Because the crystals of cast-iron are always small, and are never very well pronounced, these directions are seldom very apparent to the eye, but they are not the less real.

17. Their development depends:—

1°. Upon the character of the cast-iron itself, whether it contain a large quantity of chemically uncombined carbon (suspended graphite) or not, which Karsten has shown to be the case with all cast-irons that present a coarse, large-grained, sub-crystalline, dark, and graphytic, or shining spangled, fracture; such irons form in castings of equal size the largest crystals.

2°. Upon the size or mass of the casting, the largest castings presenting, for any given variety of cast-iron, the largest and coarsest aggre-

gation of crystals; but by no means the most regular arrangement of them, which depends chiefly upon—

3°. The rate at which the mass of the casting has cooled, and the regularity with which heat has been carried off by conduction from its surfaces to those of the mould adjacent to them; and hence it is, that of all castings in iron, those called "chilled," that is to say, those in which the fluid iron is cast into a nearly cold and very thick mould of cast-iron, whose high conducting power rapidly carries off the heat, present the most complete and perfect development of the crystalline structure perpendicular to the chilled surfaces of the casting. In such the crystals are often found penetrating an inch and half or more into the substance of the metal, clear and well defined.

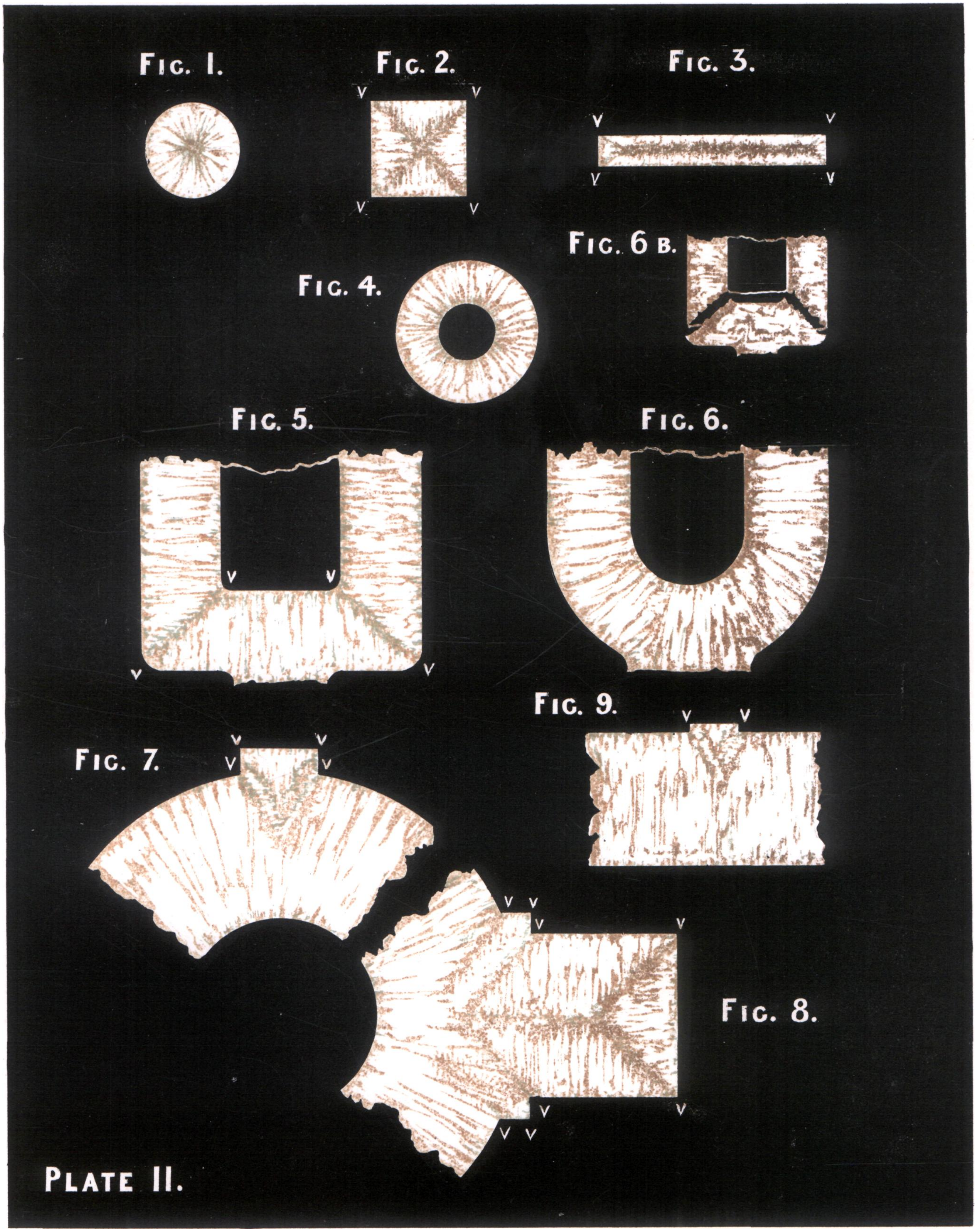
18. These prevailing directions of crystalline arrangement may be made more clear to the eye by the Plate No. II.

Figs. 1 and 2 are sections of a round and a square bar of any of the crystalline solids we have spoken of, or of cast-iron, when the crystallization is well developed (the circumstances affecting which we shall consider further on). In the round bar the crystals all radiate from the centre; in the square bar they are arranged perpendicularly to the four sides, and hence have four lines (in the diagonals of the square) in which the terminal planes of the crystals abut or interlock, and about which the crystallization is always confused and irregular.

In Fig. 3 a flat plate is shown in section. The directions of the crystalline axes follow the law of Fig. 2, with an extension in one direction.

In Fig. 4 a section is shown of the hollow cylinder of lead alluded to (page 8), in which, as in the case of Fig. 1, the arrangement of the crystals is always towards the centre, or axis of the cylinder. This figure also applies to every cast-iron hollow cylinder, whether water-pipe, gun, mortar, &c. &c.

Fig. 5 represents a portion of the lower or closed end of the cylinder of the hydraulic press as first made for the purpose of raising the tubes of the Britannia Bridge, and which broke in the attempt; the end of the cylinder having broken out from the sides in the form of a flat frustrum of a cone, as in Fig. 5 B, under the severe water pressure to which it was exposed; that is to say,



Falkner, Lith. King St Manchester

the fracture took place all round, along the plane of junction of the conterminous crystals formed perpendicular to the external and internal surfaces of the bottom and of the sides of the cylinder, proving that such planes of junction, where, as in Fig. 2 and 3, the crystals join and interlace confusedly, *are planes of weakness*—planes in which the cohesion of the metal is less and less, for this reason, than in any other parts of the mass. These *lines of weakness* extend from v to v throughout all the figures. The form of the bottom of this cylinder was changed by Mr. Stephenson, from a distinct appreciation of the fact that the fracture of the part was in some way connected with the sharp and sudden termination, square to the axis of the cylinder, though without apparently any clear conception of the crystalline laws upon which the fact depended; and a new cylinder with a sort of semiovoidal end was made—a section of a portion of which is represented in Fig. 6. This stood the strain uninjured. Here the principal axes of the crystals all are directed, as in Figs. 1 and 4, to the centre. They, therefore, gradually change their direction, and no planes of weakness are produced. (Note F.)

19. It is to be hoped that these illustrations have served to make clear the general law as applied to cast-iron artillery—that *every abrupt change in the form of the exterior—every salient, and every re-entering angle, no matter how small, upon the exterior of the gun or mortar is attended with an equally sudden change in the arrangement of the crystals of the metal, and that every such change is accompanied with one or more planes of weakness in the mass.*

20. Figs. 7 and 8 are sections of portions of a large cast-iron gun. The former, part of the breech, through the "vent-field" square to the axis of the bore; the latter, a section near a trunnion, also square to the axis. Fig. 9, a section of a reinforce ring in the plane of the axis. In all of these are shown, in an exaggerated form, the directions of crystalline aggregation, and the planes of weakness resulting from it.

21. It will be remarked that the square projection of the "vent-field" produces at each angle planes of weakness, which, in the case of the re-entering angles, penetrate deep into the thickness of the gun; and that these planes really do exist is evidenced by referring back to Plate No. I, in which it will be seen that the lines of fracture in burst guns almost always follow along the angle at the sides of the "vent-field;" so also in the case of the trunnions, Fig. 8. On

referring back to the same diagram, it will be seen that the great planes of cross fracture usually turn out and meet the exterior of the gun, just at the re-entering angle of the trunnion with the body of the gun. A gun, like every other body that fails under strain, must fail in the weakest place; we have shown in what places they do fail, and we have shown *à priori* what must be the weakest places (for a given material and mass), and we have found that the places of fracture and positions of these "*planes of weakness*" most remarkably coincide. The conclusion, therefore, seems inevitable, that however incapable the unaided eye may be to discern any difference in the crystalline arrangement of one part of the gun more than of another, such planes of weakness do exist, in the positions, and from the causes here pointed out.

22. The external forms of cannon have been greatly modified and simplified in modern times, from the complex and highly ornamented (?) forms of remoter periods; but even still, in the plainest forms of guns, such as Sir William Congreve's and Monk's patterns, &c., mouldings, astragals, reinforces, &c. &c., are still adhered to, and from the unwillingness to give up altogether antiquated forms, originally adopted and continued in ignorance, we have the folly still to cling to making numerous and useless sharp angles and corners, and sudden changes of form and of dimension on the exterior of all our ordnance, and so prolong in the most needless way one cause of their weakness. That gun, however plain externally, will look best to the really educated eye, that most fully conforms to the laws upon which its perfection as an instrument depends.

5.—*Physical Conditions induced in Moulding and Casting.*

23. Some remarks must now be added as to the effects upon the strength of guns, which circumstances brought into play in the processes of moulding and casting them exercise, extraneous to those which we have already treated of, as respects the conditions of aggregation of the crystals of the metal.

It is not my intention to go at any length into questions referring properly to the iron-founder's art; to practical methods, better or worse; or to the details upon which sound or defective castings depend. These, though most important, do not find a fitting place here. But I purpose to consider:—

1°. Upon what circumstances the more or less complete homogeneity of the crystalline alloy we call cast-iron depends, when cast into guns; and, therefore, how with the best, or with any, external form, we may most avoid the formation of "planes of weakness," so far as the moulding and casting are concerned.

2°. The effects due to the contraction of the metal in process of cooling, and of sudden changes of mass or of dimension and form upon this.

3°. The effects of rapid and of slow cooling, and of unequal cooling.

4°. The effects of casting under the fluid pressure due to increased "head" of molten metal.

And to add a few remarks upon the presumed relative advantages, so much and so loosely talked of latterly, of cold-blast and hot-blast iron, and of foreign and British iron, as materials for ordnance.

24. It is known to every practical iron-founder upon a large scale, that, generally, the larger the mass of the casting he makes with any given quality of cast-iron, the "*coarser is the grain*," that is, the larger are the crystals that develop themselves in the mass. The same metal that shall produce a fracture, bright gray, matted, and without a crystal visible even to a single lens, in a bar, cast, say, two inches diameter, shall, if cast into a cylinder of two feet in diameter, produce a dark, confusedly crystalline surface of fracture, as coarse as granite rock.

To meet this, the practice is to prescribe for material for large castings a certain large proportion or mixture of "small, close-grained scrap metal," with the pig-iron, of whatever best quality may be denoted. The remedy fails—as fail that always must which is founded upon a misconception of the laws of the phenomena. As well might small seeds be sown to produce small trees. The small scrap is no sooner recast into the large mass than it resumes the large crystalline grain.

25. The experiments of Mr. Fairbairn (Trans. Brit. Ass., 1853) on the repeated melting of the same cast-iron, by casting into inch-square bars, are concluded by him to prove that the grain of the metal and the physical qualities of the casting improve by some function of the number of meltings; and he fixes on the thirteenth melting as that of greatest strength.

Some most important conditions, modifying if not invalidating such a conclusion, and more especially the effects of the variable *mass* of the casting, seem, however, wholly to have escaped him. Indeed, these experiments, rightly considered, only prove what was well known before—that by continually re-melting and casting into *small* pieces (i. e., imperfectly chilling) any cast-iron, we may gradually cause all its suspended carbon (in the state of graphite) to exude, as Karsten long ago proved, and so gradually convert the metal into an imperfect steel, with increased hardness and cohesion, and diminished fusibility, but with properties altogether unworkable and useless. No such result can occur when the metal is cast into large masses, nor any such assumed improvement by repeated meltings, but very much the contrary. (Note G.)

26. Again, by some iron-founders, one "make" or sort of pig-iron is presumed to give a closer grain than another, and he prefers it; and although this is to a certain extent true, i. e., that some cast-irons, that is, some of the innumerable alloys that go under that name, do under equal conditions produce rather smaller crystals than others, still this view equally fails to attain the object of close-grained, heavy castings. But furthermore, it is a fact familiar to iron-founders, that of several castings of the same form and mass, made at nearly the same time, from the same mixture of metal, and melted in the same furnace, some will, when cold, have a much more coarsely crystalline grain developed in them than others. The fact is familiar; but I am not aware that any attempt has been made on principle to explain it, and hence no means have yet been prescribed to prevent its occurrence.

27. Now while the *regularity of development* of the crystals in cast-iron depends, as we have already seen, upon the regularity with which the melted mass cools, and the wave of heat is transmitted from its interior to its surface, arranging the crystals in the lines of least pressure in its transit,—*the extent of development*, or, what is the same thing, the size of each individual crystal, depends upon the length of time during which the process of crystalline arrangement is going on, that is to say, upon *the length of time that the casting takes to cool.* Hence, then, may be announced as a law, that—

28. The size of crystals or coarseness of grain in castings of iron depends for any given "make" of iron, and given mass of casting, upon—

1°. The high temperature of the fluid iron above that just necessary to its fusion, which influences—

2°. The time that the molten mass takes to cool down and assume again the solid state.

29. These laws have very recently received the most striking confirmation from some quite analogous researches "Upon the Molecular Properties of Zinc," made by Mons. P. W. Bolley, and published in the "Annalen der Chim. und Pharm." st. xcv. p. 294. Zinc and iron are bodies so closely allied in all their properties, chemical and physical, that in almost everything that relates to the latter, analogy holds in the most striking manner, and this proves to be so here,—where M. Bolley's results, arrived at, in all probability, without even a knowledge of the facts above adverted to as affecting cast-iron, are found perfectly in parallel.

His paper scarcely admits of extracts: it will suffice, however, to state his chief results. He finds that zinc, of whatever sort, whether chemically pure, or alloyed with various minute foreign metals, as found in commerce (just like cast-iron), is capable of crystallizing upon cooling from fusion in two distinct forms. In one, the fracture presents a small-grained, uniform, confusedly crystalline surface, it is "grenué." In the other, large, well-formed lamellar crystals, with their principal axes, standing perpendicular to the bounding surfaces of the cooled mass, well known to all who have seen a commercial ingot of zinc broken, are produced.

He proceeds to investigate the conditions under which these two states of aggregation occur, and he finds they have nothing to do with the purity of the zinc (as respects extraneous alloying metals, or even the carbon that it contains, always more or less of), nor with the sort of original crystalline aggregation of the zinc used for experiment, i. e. whether in large or small crystals; but that it depends upon the higher or lower temperature at which the zinc is fused and poured into the mould, and upon the rate at which it is cooled down to solidification.

Thus, if zinc be heated just to its fusing point (773° Fahr.), and no higher, and be then cast in the mould—

Its crystalline grain on fracture is (grenué) small, fine, and confusedly crystallized.

Its specific gravity is as great as 7·18.

It has (as compared with zinc aggregated in large lamellar crystals) a slower solubility in acids.

It has greater malleability, and a greater extreme range of temperature within which it remains malleable. (Note H.)

But if the same zinc be not merely fused, but heated up to a red heat, and so poured into the mould, then, when solid—

Its crystalline grain on fracture is coarse, large, and lamellar.

Its specific gravity is only 6·86.

It dissolves more rapidly in acids than the former; and

It has scarcely any malleability at any temperature.

And these results are the same, *relatively*, whether in either case the zinc mass be let to cool slowly in the mould, or be taken out as soon as solidified, and suddenly cooled in water.

M. Bolley thinks it probable that zinc may be dimorphous, taking the form of the regular system when crystallizing from a high temperature, like copper, gold, lead, silver ; and the rhombohedric, like bismuth, antimony, arsenic, tellurium, when crystallized from *just* its fusing point, and so indicating relations of a crystallometric character with platina, iridium, and palladium, whose atomic volumes are almost the same as that of zinc. Whether this explanation, which does not commend itself to me as probable, be so or not, the fact is clear, and, coupled with our previous knowledge, may with confidence be applied to cast-iron ; and the conclusion and rule be thence deduced, one of the utmost importance to obtaining serviceable cast-iron guns.

30. That the lower the temperature at which the fluid cast-iron is poured into the mould, and the more rapidly the mass can be cooled down to solidification, the closer will be the grain of the metal ; the smaller its crystals, the fewer and least injurious the "planes of weakness," and the greater the specific gravity of the casting, *cæteris paribus*.

31. Practical iron-founders are in the habit of judging of what they deem by experience the best temperature of the fluid iron for being poured into the mould, by a certain peculiarity in the form of the vorticose movements that go on upon the surface of a mass of fluid iron, and called technically "the breaking" of the iron. This test, however, is perfectly empirical and fallacious. The very lowest temperature at which the iron remains liquid enough fully to fill

every cavity of the mould, without risk of defect, is that at which a large casting, such as a heavy gun, ought to be "poured." As respects the rapidity of cooling desirable, we shall be enabled presently to consider the conditions that determine the extent to which it may be safely carried.

32. A certain amount of contraction on becoming solid from the liquid state occurs in all castings. It is well known to practical founders that for cast-iron this is variable, and depends upon the mass of the casting, being greatest for small and least for large castings of the same "make" of iron; but it is obvious, and it follows from M. Bolley's researches, that the contraction also will be greater in proportion as the metal is poured into the mould at a higher temperature, although, from the expansion in the act of crystallizing, the specific gravity of the solid mass may be less at the higher than at the lower temperature of "pouring."

33. As, therefore, there are two conditions that principally affect the degree of contraction—the total change of volume between the liquid metal and its solid casting; namely, the extent to which the fluid metal as entering the mould has been expanded by elevation of temperature and the state of final aggregation of the crystalline particles—which we have seen depends much upon the former—so there will be a determinate amount of contraction due to a determinate thickness or mass of casting, irrespective of, though also related to, the coefficient of contraction for any particular "make" of iron; for there is no doubt that different makes, *cæteris paribus*, contract somewhat differently. From whence it follows, that different parts of the same casting, if differing materially in scantling or mass, will have different amounts of final contraction; and hence—

34. Sudden changes of form or of dimensions in the parts of cast-iron guns, besides the injury they do to the crystalline structure of the mass, introduce violent strains, due to the unequal contraction of the adjoining parts, whose final contraction has been different.

How desirable is it, therefore, to introduce such alterations of the forms of our ordnance as shall avoid those sudden and enormous (and often useless) changes of adjacent mass, that we observe; as for example, in the sea and land service 13-inch mortars, where at the chamber (where the strain being as D'' is least) the thickness of metal suddenly approaches twice that of the chase—a malconstruction the full evils of which we have yet to consider.

35. The amount of *lineal* contraction due to solidification of cast-iron appears to vary with metal and circumstances of casting, from $\frac{1}{120}$ up to $\frac{1}{90}$ of the dimensions of the cold mass. Its contraction in *volume*, therefore (more than three times this), and probably not equal in the directions of three rectangular axes, owing to the crystalline structure, is so great, and the difference such, between its measure for large and small parts of the same casting, that the latter never should be neglected.

36. The effects of this difference are well known to founders by causing castings of certain forms to become distorted or spontaneously broken after they have solidified. To multiply instances would be tedious; but one circumstance requires remark, as proving that these internal strains occurring in castings of variable bulk exist where little suspected, and that it is with extreme slowness that the molecules after consolidation appear gradually to assume minute changes of arrangement, and to adjust themselves, within certain limits, to a state of permanent equilibrium.

37. It is a fact known well to working mechanics engaged in boring or turning or otherwise cutting into large castings of iron that have cooled safely and without crack or flaw, that yet when a part of the whole mass shall have been cut away—as for example, when a large and thick-flanged cylinder, or a large toothed wheel, or other irregular discoid mass, is "bored out," the form of the exterior of the mass changes during the operation. The portion cut away destroys the temporary equilibrium that was established in the mass, and it again changes its form, and perhaps its symmetry, and sometimes even its volume.

38. For some most valuable illustrations of the singular forms or lines of direction which the curves of internal tension and compression take in solids of various forms thus under elastic constraint, Mr. Maxwell's paper in the Transactions of the Royal Society of Edinburgh, vol. xx. part i., may be consulted.

They bear a remarkable analogy to the nodal lines of Chladni and Savart traced by their researches on the vibrations of sonorous plates, and are directly connected with the optical properties first shown by Sir David Brewster in glass under constraining forces.

39. Sometimes a casting which has cooled safely will fly to pieces on receiving a sudden jar or blow, of a trifling degree of force—a fact which is in analogy

with that observed by Captain Parry in his earlier Arctic voyages—viz., that the astronomical instruments exposed to extremely low temperatures for long periods, and quite undisturbed, did not contract to their extreme point until after they had been subjected to some slight jar or blow, when the metal of the instrument *suddenly* became reduced in volume, and its dimensions again stationary.

40. The extreme slowness, continuing sometimes for months, with which these molecular changes take place, due to the gradual adjustment of such internal strains, has been beautifully shown in a memoir on the elastic properties of solids (Annales de Chimie, vol. xli. p. 61), by M. Savart, who found that plates of sulphur cast into flat discs continued to change their state of molecular arrangement for long periods after solidification.

41. It follows from this that old guns that have long been bored and laid in store are likely to be more trustworthy than those hastily cast, bored out, and brought into service; and this seems to be supported in some degree by experience.

42. In general extension and support of the views I have advanced as to castings in iron becoming endowed with variable powers of resistance depending upon external form and mode of casting, &c., the important memoir of M. Savart above alluded to should be consulted. By refined and delicate methods of investigation founded upon sonorous vibrations elicited, he has shown that numerous bodies, such as zinc, lead, cast copper, glass, plaster of Paris, sealing-wax, and others, though possessing apparently a perfectly homogeneous structure, have it not; but, on the contrary, all possess lines or planes usually crossing each other at right angles, in which their resisting powers are enfeebled, and which he has called *axes of greatest and of least elasticity*, and which he attributes to the arrangement of their molecules assumed in the process of cooling. The relations of these phenomena to the conditions of cooling and external form of the body as affecting these, however, do not appear to have been perceived by M. Savart, and the author of this paper believes have been here stated in a distinct form for the first time.

43. Besides the effects already referred to, due to the contraction of cast-iron in becoming solid, another class of *abnormal strains introduced by the consolidation of one portion of a casting before another*, must not be passed over, as often

producing results of the most important character in artillery. This will be more readily understood by immediate reference to example. When a large gun, or, still more, a large mortar, is cast solid, and the metal cools in the ordinary way, the external portions solidify long before the interior has ceased to be liquid, and the process of solidification is propagated, as it were, in parallel "couches" from the outside to the centre of the mass. The lineal contraction of any one couche assumed of indefinite thickness is in the direction of its circumference directly proportionate to that circumference; and so it would seem (at first) that the contraction of the whole assemblage should be at every point proportionate to its distance from the centre, and that so the solid, when all cold, should be left in a state of molecular equilibrium. This is not the case, however; for no sooner has the first couche or thickness of solid crust formed on the exterior, than it forms a complete arch all round, so that the contraction between fluidity and solidification of each subsequent couche is accommodated (the continuity of the mass remaining unbroken throughout) by portions of matter *withdrawn radially from the interior* towards the still cooling exterior; that is to say, from a smaller towards a larger circumference. The final effect of this, propagated to the centre of the mass, is twofold:—

1st. To produce a violent state of internal tension in the molecules of the metal, in radial lines from the axis of the gun viewed as a cylinder, tending to tear away the external portions of the mass from the internal nucleus; a force which is zero at the axis and at the exterior, and a maximum between and probably at a point of the radius somewhere between R and $\frac{R}{2}$ from the exterior.

2nd. To produce about the centre or along the axis a line of weakness, and one in which the texture of the metal is soft, porous, of extremely low specific gravity, with coarse and frequently, distinctly separated crystals, and often (notwithstanding the precautions of the founder in "feeding" the "head of the casting"—that is to say, in slowly adding fresh quantities of hot and fluid metal while ever it is possible to get it introduced into the centre of the solidifying mass), leaving actual cavities in the centre of the casting.

44. In a casting of two or three feet or more in diameter, it is not unusual (with the founder's best care) to find a central portion of from 6 to 8 or more

inches in diameter, consisting of a spongy mass of scarcely coherent crystals of cast-iron, usually in arborescent masses, made up of octohedral crystals; the whole so loose that upon a newly-cut section dark cavities can be seen by the naked eye in all directions, out of which often, single or grouped crystals can be picked with the hand, and so soft that a sharp-pointed chisel of steel may be easily driven into the mass some inches, as if into lead or soft stone. It fortunately happens that in pieces of artillery a large portion of this defective core of spongy metal is removed in the process of boring out; but where the hollow taken out thus, does not extend very close back to the exterior of the breech—in other words, where the thickness of the breech in the line of the axis is considerable, a portion of the spongy uncompact metal is left remaining, and forms the part of the gun at the bottom of the bore or chamber. This is most remarkably the fact in large mortars. An absurd adherence to a false analogy with long guns, or to antiquated routine, compels all mortars in our service still to be cast solid, and then bored out. The diameter of the mass is great in a 13-inch sea mortar—about 3 feet 4 inches. The mass of metal left below the chamber when bored out, is immense, and quite useless. The effect of both is, that every mortar has got a "soft spot," just at the bottom of the chamber, and extending downwards from it in the line of the axis; and that every part of the chase of mortar is in a state of violent molecular strain, from the consolidation of its external walls, long before the interior portions; and hence weakness in the whole piece.

45. Fig. 1, Plate III., is a section in line of axis, and plane of trunnions, of a 13-in. sea mortar, with the head of metal remaining attached, and the whole in the position in which the mortar is usually cast, with the parts to be cut off and to be bored out marked by and above a black line, exterior to which is the finished mortar. The shaded central portions represent the weak and porous parts of the metal about the axis, extending down, it will be observed, below the bottom of the chamber, where it leaves a soft spot, easily hammered and burnt away, by the shock and blaze of the powder. From the conditions of internal strain already explained, the *exterior* of the cylinder is in a state of *compression*, and the *interior* in a state of *tension*, a state (as we shall show hereafter) precisely the reverse of that calculated to give the metal its greatest power of resistance to internal strains in the direction of the radius.

These phenomena are plainly brought into evidence in mortars; but they exist, in less degree, in cannon, though, from the length of chase of the latter, it is extremely difficult to make any perfect examination of the state or quality of the metal at the bottom of the bore.

46. Figs. 2, 3, 4, and 5, Plate III., represent portions of castings, in section, of various external forms, in which sudden changes of volume frequently produce internally actual cavities, technically known as "draws" amongst workmen. Fig. 2 is an excentric shell. Fig. 3, partial section of a girder, with a *thick* base rib, and *thin* vertical web. Fig. 4, part of a *heavy* flat casting, with a *thin* flange projecting from it. Fig. 5, part of the upper (or mouth) portion of the cylinder of an hydraulic press (one which occurred in the author's practice), but quite similar to the conditions so well described by Mr. Edwin Clarke, of the first defective cylinders cast for raising the Conway and Britannia tubes.

47. These internal cavities are usually found more or less perfectly lined with adherent crystals of cast-iron, and with plates or crystals of exuded graphite. The figures given sufficiently illustrate their general character. The main or longest directions of these irregular cavities always tend to follow the "planes of weakness," or to place themselves, at right angles to these.

Their magnitude depends upon—

1°. The coefficient of cubic contraction of the particular "make" of cast-iron.

2°. The high temperature at which the fluid metal has been "poured," i. e., the length of range of temperature through which it has cooled, and the inefficiency with which the mass has been subsequently "fed" while solidifying.

3°. The mutual relations as to volume of the adjacent and successively solidifying parts of the whole mass.

No British makes of cast-iron are so subject to violent "draws" as the best and toughest of the South Wales irons, such as the Blaenavon, &c.

6.—*Effects of Bulk and Fluid Pressure.*

48. It is a remarkable fact, though one not yet fully explained, that a small bar, cast on-to, or projecting from, a casting in iron of very large scantling, when afterwards broken off and tested, will not sustain, by a good deal, as great a trans-

Fig. 1.

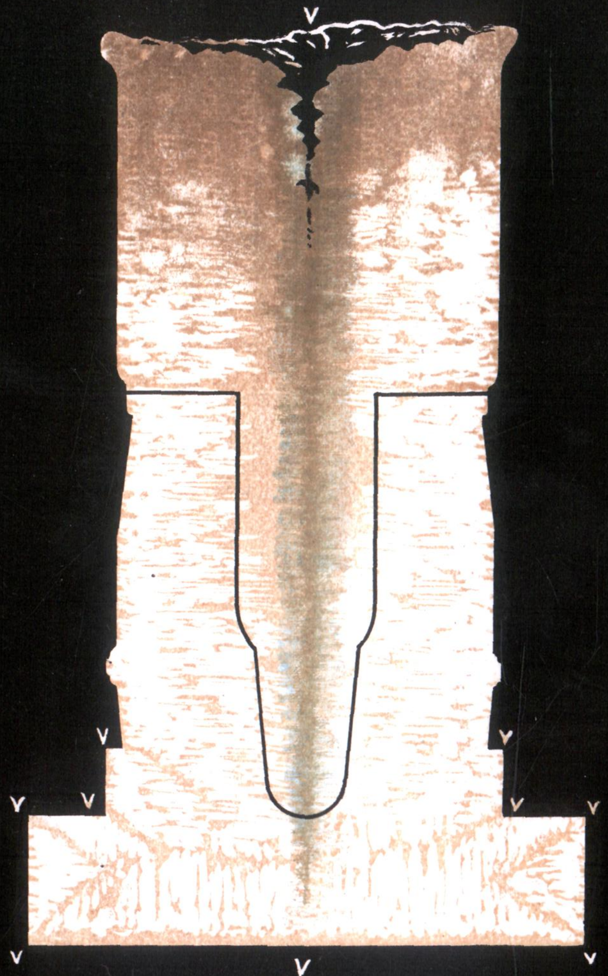


Fig. 4.

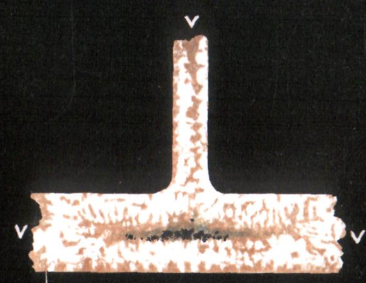


Fig. 3.

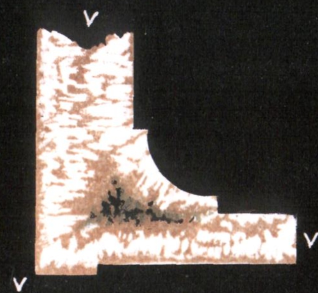


Fig. 5.

Fig. 2.

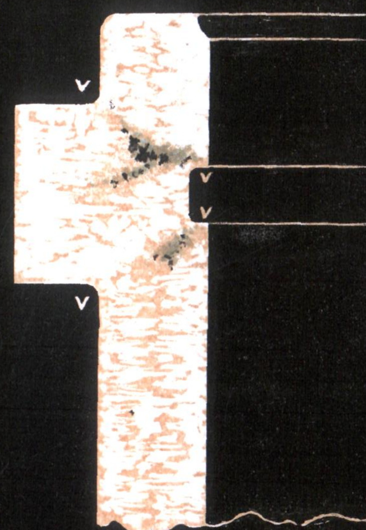


Plate III.

verse or longitudinal strain as the same sized bar, of the same metal, cast alone (i. e. in an isolated mould), and under the same "head" of metal. This circumstance, no doubt due to the conjoint influence, of several of the molecular conditions that have been under discussion, appears to be in part due to the extreme slowness with which the small bar cools in close proximity to the large mass of which it forms an appendage.

49. It was most probably owing to this cause that Mr. Hodgkinson found the specific gravity of the *thin* webs, of the cruciform section of castings, adopted by him for experiments on the extension of cast-iron, under tractile forces, to be less than that of the parts of the same bar having *greater bulk*. The fact seems to conflict with the general one ascertained by me, that the specific gravity of castings is less in proportion to some function of their increased volume, as shown in Table I., following.

The law, however, enunciated in this Table applies to the average specific gravity of *separate* masses of *similar form*, *but different volume, and cast each in a separate mould, and in the same way*, and is, therefore, not affected by Mr. Hodgkinson's case.

50. Slow cooling developes a coarse, uneven grain, with large but thoroughly irregular and confused crystallization. Cast-iron with such a grain is never strong or cohesive, though perhaps soft and extensible. The more rapidly a casting once consolidated can be cooled, without introducing injurious effects, the finer, closer, and more even will be its grain on fracture, and with any given metal the greater will be its strength. The rate of cooling cannot be accelerated beyond a moderate limit. If this limit be exceeded, as by casting in a cold, thick, highly conducting metallic mould, the iron is "chilled," its chemical, or, at least, its mixed constitution changed, and the uncombined graphite is exuded, the combined carbon only remaining in the white chilled metal. It cannot be so fast as to endanger unequal contraction, nor must it be so fast in large castings, such as guns requiring to be "fed" from a "feeding head," with fresh portions of hot fluid metal during consolidation, to fill up the internal cavities or porosity due to contraction and crystallization, as already explained, that this feeding cannot be accomplished. The prevalent notion, however, that the soundest and strongest castings are obtained by letting them cool slowly in the moulds, is founded on a radical error.

51. The enormous time required by a large casting for cooling, especially if left to cool *in the mould*, and hence "jacketted," with its badly conducting material (clay and sand) is not generally known. The hydraulic press cylinders for raising the Britannia Bridge tubes, which were about 12 feet long, and about $3\frac{1}{2}$ feet diameter, and weighed in the mould, perhaps, 20 tons, were found red hot at the expiration of seventy-two hours after having been cast, and only became cold enough to handle ten days after being stripped from the loam, and required "feeding" for more than six hours after having been poured. During the greater part of this time, molecular changes were going on, increasing the coarseness of the crystalline grain of the metal, and reducing its tenacity. It would have been much better practice to have kept the exterior of "the loam" wet, and thus induced cooling by evaporation, as soon as ever the "setting" of the metal had rendered it safe to do so.

52. The cooling must be uniform, so far as uniformity is possible. This is impossible, strictly, in any casting; the approach to it is most difficult, in heavy solid castings, such as guns and mortars, and hence the great advantage that would result from a return to the antique practice of casting them hollow upon suitably made "cores," as admitting of internal cooling by artificial means, such as a current of air, at the same time that the outside is cooling. It is understood that the American Government so requires its guns cast, and cools them by a current of water passed into the interior—a practice of very doubtful advantage, as not under sufficient control to insure avoidance of an evil greater than that it is proposed to remedy, namely, cooling the interior of the gun much faster than the exterior.

53 Unequal cooling, especially if very rapid, involves all the injury, that violent internal wrenching and straining can do to strength,—strains of the very same character as those under which it is part of the purpose of this paper to show, that guns burst, and which often, in the every-day practice of the iron-founder, result in actual fracture.

54. Guns have long been cast in a vertical position, and with a certain amount of "head" of metal above the topmost part of the gun itself: one object gained by this (of great value) is to afford a gathering place for all scoria or other foreign matter, an end that might be much more effectually accomplished, were the metal always run into the cavity of the mould by "gaits" leading to the

bottom or lowest point, in place of the metal being thrown in at the open top, with a fall at first of several feet, as is now the common practice, by which much air and scoria are carried down and mixed with the metal, some of which never rises up again, or escapes as "air bubbles." But the great value of increased head of metal, in adding to the density of castings, and so also to their strength, appears so little generally known, or, if recognised, is so seldom attempted to be practised, to any considerable extent, i. e. depth of head, that I am induced here to repeat the Tables XII. and XIII. from pp. 304 and 305 of my Second Report on Iron, Transactions of the British Association for 1840, in which the results are given of some extended and careful experiments made by me, to ascertain the relation between the head of fluid pressure and the specific gravity of the casting.

55. My experiments were made upon cylindrical shafts of cast-iron, cast vertically, in dry sand moulds, and under heads gradually increasing up to fourteen feet in depth; and all poured from "gaits" at the bottom.

TABLE I.

Showing the increase of Density in Castings of large size, due to their Solidification under a head of Metal, varying from two to fourteen feet in depth.

No. of Experiment.	CALDER CAST-IRON, No. 1. HOT BLAST.			BLAENAVON, No. 1. COLD BLAST.			APEDALE, No. 2. HOT BLAST.			Quam prox. Pressure when fluid, in lbs. per square inch.
	Depth of Casting in inches.	Specific Gravity.	First Difference.	Depth of Casting in inches.	Specific Gravity.	First Difference.	Depth of Casting in inches.	Specific Gravity.	First Difference.	
1	0	6·9551		0	7·0479		0	7·0328		·0
2	24	6·9633	·0082	24	7·0576	·0097	24	7·0417	·0089	6·4
3	48	7·0145	·0512	48	7·0777	·0201	48	7·0558	·0141	12·8
4	72	7·0506	·0361	72	7·0890	·0113	72	7·0669	·0111	19·2
5	96	7·0642	·0136	96	7·1012	·0122	96	7·0789	·0120	25·6
6	120	7·0776	·0134	120	7·1148	·0136	120	7·0915	·0126	32·0
7	144	7·0907	·0131	144	7·1288	·0140	144	7·1046	·0131	38·4
8	168	7·1035	·0128	168	7·1430	·0142	168	7·1183	·0137	44·8

These experiments show an increase of density due to 14 feet head about equal to a pressure of 44·8 lbs. per square inch on the casting, from 6·9551, to 7·1035 for Scotch cast-iron.

56. In the following Table, No. II., the *decrease of specific gravity following increase of bulk* is obtained.

TABLE II.

Showing the decrease of Specific Gravity, due to increase of bulk, of Iron Castings made from the same sort of Cast-Iron, and under similar circumstances.

Mark of Experiment.	CALDER, No. 1. HOT BLAST.			BLAENAVON, No. 1. COLD BLAST.			APEDALE, No. 2. HOT BLAST.		
	Dimensions of Casting.	Specific Gravity.	First Difference.	Dimensions of Casting.	Specific Gravity.	First Difference.	Dimensions of Casting.	Specific Gravity.	First Difference.
	Inches.			Inches.			Inches.		
A	5 × 5 × 0·25	7·0560	·0299	5 × 5 × 0·25	7·1449	·0015	5 × 5 × 0·25	7·1876	·0141
B	5 × 5 × 0·50	7·0261	·0366	5 × 5 × 0·50	7·1464	·0041	5 × 5 × 0·50	7·1735	·0571
C	5 × 5 × 1·	7·0627	·0771	5 × 5 × 1·	7·1423	·0270	5 × 5 × 1·	7·1164	·0358
D	5 × 5 × 2·	6·9856	·0268	5 × 5 × 2·	7·1153	·0211	5 × 5 × 2·	7·0806	·0323
E	5 × 5 × 4·	6·9588		5 × 5 × 4·	7·0942		5 × 5 × 4·	7·0483	

57. For the relations that both head and bulk of casting appear to bear to strength, see the observations at page 270, Report (*ut supra*). Fineness of grain, smallness of crystal, density, increased cohesion and elasticity, and diminished corrodibility by chemical agency, all are induced by casting under largely increased statical heads of fluid metal. Let us hope so evident an improvement may no longer be neglected in our gun-foundries, where, by apparatus not difficult to contrive, atmospheric pressure, or that of condensed air, might easily be brought to aid that of the head of metal, with economy in reducing the labour and cost of the mass of metal to be melted, and with the advantage of enabling the pressure on the solidifying mass to be varied, or repeatedly increased *per saltum*, so that by a certain amount of regulated momentum, the consolidating particles should be pressed and shaken into contact.

7.—*Quality of Metal.*

58. The repeated failures of cast-iron ordnance latterly, and a very imperfect and uninformed appreciation either of the causes, or of the respective qualities of various "makes" of cast-iron, have induced the belief and expression of doctrine "on authority," that the failures have been owing to the use of British makes of cast-iron; that smelting with pit coal produces effects highly injurious to the tenacity of the pig-iron, &c., &c.; and that the remedy is to be sought in the employment of foreign cast-iron, smelted with charcoal only, such as that of Nova Scotia or Sweden; and a certain plausibility is given to this half-fledged

theory, by the instance that "a Swedish or Russian gun is never known to burst," and that American and Swedish guns, even field-guns, are now fabricated of some similar iron.

The whole is a fallacy. There is no just reason to believe that any stronger pig-iron is to be found from abroad than many well-known "makes" of Great Britain. The fault is not in the iron, but in the want of skill to choose what sort of iron to obtain from the blast furnace in the first instance, and how to recognise and choose it for gun-founding, in the second.

59. "Fine-grained gray mottled iron," it is constantly and truly said, is that best fitted by tenacity and by elasticity for ordnance. But how is this in England continually attempted to be obtained? By mixing a perfectly white lamellar No. 4 pig-iron, or "scrap metal," equally intensely hard and infusible, with some soft, micaceous, or largely and coarsely graphitic dark gray, or almost black No. 1 Scottish or Staffordshire pig-iron. The two, possessing totally different fusibilities, may be *imperfectly mixed* together, but they cannot be *combined* by mixture. They form a mass of coarse mottled iron, with large black dots of flat scales of graphite in a white ground, more or less like "hornblendic granite," having a low density and small cohesion and elasticity. (Note H.)

60. Let us observe what one of the ablest metallurgists of iron in Europe, Karsten, a man well acquainted with Swedish iron industry, says as to the modes by which the iron is chosen for those very Swedish guns:—"The tenacity of gray cast-iron is much less in proportion as the metal has received a more intense heat in the blast furnace, and if we require castings to give a very great resistance we must not employ it; that which is obtained from less refractory ores, and in furnaces of lower temperature, answers much better for castings demanding much strength, provided that it be not too gray [too graphitic], and that it do not expel too large a quantity of graphite [in cooling, namely], which often gives rise to breaches of continuity in the interior. [Note I.] In certain cases we must neither use one sort nor the other of iron [viz., neither gray iron nor white, of which he before had spoken]. Cannon, for example, must not be cast from gray cast-iron, especially when produced from a mixture of refractory ores and flux, because then it contains always a large proportion of earthy metals; but even with readily fusible ores it is extremely difficult so to work the smelting furnace that the pig-iron shall neither be too gray nor too white, either of which is equally injurious for gun-founding.

"In Sweden they remedy this difficulty in the following way:—the charge for the furnace is made up partly of roasted ore and partly of raw ore, and the furnace is so kept in blast that its yield shall be regular, and the slag good (i. e. nearly colourless). *There is thus obtained a pig-iron, very closely mottled*, made up of white lamellar iron, and of dark gray iron, like the usual mixed qualities of pig-iron. It is obvious that these two sorts of ores, having two different degrees of fusibility, are reduced after different periods in the furnace, and hence afford, one of them gray, and the other white iron. If the minerals be properly proportioned, there is obtained a very finely mottled gray iron, which is *less porous*, *harder*, and *more tenacious* than the gray irons obtained by the ordinary methods [of mixture, namely on remelting in the cupola]."

He then proceeds to describe another method of working the blast furnace, by which similar results may be obtained, and concludes:—"By these means we may determine to pig-iron any proportion of carbon we please; the metal becomes more tenacious, expels less graphite [in cooling, namely], and never shows spongy cavities after cooling."—Karsten, *Handbuch der Eisenhuttenkunde*. (Note I.)

61. M. Kulmann, also, in his Lectures on the Manufacture of Projectiles, &c., for the Artillery School of Metz, gives a precisely similar account; in a word, to obtain the very finest quality of cast-iron for gun-founding, all that is necessary is the use of a small-sized blast furnace, such as those occasionally found in Staffordshire, a very gentle blast, and a heavy charge of ore and flux, in the mixed form above directed. A low temperature must be preserved in the furnace;—the production of dark gray, graphytic iron resulting always from intensity of heat.

62. The use of charcoal in place of pit-coal, or coke, does not appear essential. Many "makes" of British iron, smelted with sulphur-bearing coal, yet afford no sensible traces of sulphur on analysis; its exclusion being always capable of being insured by a proper mode of working the furnace, while the recent researches of M. Janoyer, Director of Iron Works in the south of France, appear to indicate that by the judicious use of a certain proportion of phosphatic ores, along with our ordinary clay ironstones, sulphur may be completely eliminated from the iron, the sulphur being replaced permanently by phosphorus, and going off as sulphuret of carbon.

63. Neither does the use of cold blast appear indispensable, although greatly

facilitating the preservation of that moderate temperature in the blast furnace, upon which the production of the desired sort of iron depends.

64. But the working of a small blast furnace, at a low temperature, and in the method above described, produces necessarily a small daily yield of pig-iron —it, therefore, will not pay; and hence will not be adopted by any maker in Great Britain, unless insured a proportionally remunerative price for his manufacture of a special pig-iron, destined and well fitted for the manufacture of our national ordnance. If such an inducement be given, makers may soon be found to produce pig-iron, *better* fitted for gun-founding than any foreign iron.

65. It is a mistake to suppose that the foreign charcoal cast-irons have a greater tenacity generally than our British "makes;" the reverse is the fact, and equally so with wrought-irons. In proof of this I may quote the results of a most carefully conducted and extensive series of experiments made under the direction of the late Mr. Tierney Clarke, C. E., with reference to the relative strengths of Hungarian and Austrian cast-irons as compared with British; the former were proposed being used in certain parts of the suspension bridge across the Danube at Pesth, in Hungary, exposed to transverse strain.

General Results of Experiments on Hungarian Cast-Iron at Pesth.

Transverse strain, reduced to bars of 3 feet bearing, and 1 inch square.

Count Andrasi's Iron, Dernö,	821·515 lbs.
Hoffman, Brothers, Madersbach,	651·996 ,,
Concordial Works, Sébok,	675·655 ,,
Pesth Foundry,	813·021 ,,
Baron Rothschild, Styrian,	964·080 ,,
General average,	785·253 lbs.

Load in middle.—All Cold-Blast Iron.—Banks' experiments, quoted by Barlow, p. 221, gave a mean of 844 lbs., and were Cold-Blast, agreeing very nearly with Tredgold's for Staffordshire Cast-Irons, also Cold-Blast.

To these might be added sufficient proofs that, generally, the European cast-irons made with charcoal, are not as strong (taking all the conditions which the word embraces) as the best makes of British cast-iron.

66. Again, as respects wrought-iron, if the numerous tables of experimental strength, published by Karsten, Vicat, Le Blanc, Dulean, and others, be examined, it will be at once seen that few continental "makes" of iron (even charcoal iron) equal in strength our best British irons. As regards the special

results of charcoal smelting and refining, it was remarkable that in the Belgian Departments of the Exhibition of 1851, the MBR. Ardennes charcoal-iron, certified "never to have produced a musket-barrel that burst," stood beside the *coke-made* iron wire of Orban and Sons, certified to stand a strain of above 40 tons to the square inch. The experiments made on the Samakoff and Elbese charcoal irons, and recorded (Proc. Ins. Civ. Eng., vol. iii. p. 225), prove also their great inferiority in strength and elasticity to the vast mass of British makes.

Some valuable Tables of comparative strength of French with British and foreign wrought-irons may be found in a Paper by M. Martin ("Du Fer dans les Ponts Suspender," &c. Ann. des Mines, 3ieme Ser., t. v. p. 68). These experiments were made by Colonel Barbe and M. Bornet, at the Iron Works of Chamond and of Fourchambault.

It would be tedious to quote these authorities even in extract; but the result may be given in the words of MM. Flachat, Barrault, and Petiet, in summing up these experiments:—"The mean resistance of these irons (the best that France, at the time (1845) could produce) is about 35 kilos. to the square millimetre; and cable irons being always made with much care, are therefore stronger than the majority of ordinary irons, while the experiments made in England by Telford and Brunel give resistances of from 40 to 50 kilo. to the square millimetre."—*Fabric. de la Fonte et du Fer.*

67. It has been repeatedly proposed and abortively attempted to improve the quality of cast-iron for guns, by the admixture of some foreign metal in minute proportion. Copper, it was affirmed by Hassenfratz long ago, added much to the tenacity of cast-iron. This alloy was formed, and some experiments made on it by the younger Bramah, as recorded by Tredgold, and it is affirmed to have been adopted by Perkins, for closing the porosity of cast-iron when applied to the cylinders of hydraulic presses. Tin, lead, tungsten, manganese, have also been tried, but none to any good purpose, nor could any be justly anticipated; the affinities of iron in forming alloys are very slight, and its previous combination with carbon, for which it possesses so powerful an affinity, seems to reduce the former to so low a point that its alloys are little better than heterogeneous mixtures which separate by eliquation on cooling.

68. Want of assured homogeneity, especially in large masses, appears also to be the objection to "Stirling's patent toughened iron," i. e. wrought-iron fused in mixture with cast-iron, nor is it easy to see how his method gives a result

better than what is attainable by the admixture of a proper selection of different cast-irons alone,—though well deserving a much more careful course of experiment on the part of the gun-founder, than has yet been devoted to it. Much stress has been laid by some, too, upon the melting being performed in air furnaces in preference to cupolas urged by blast. The only real difference as respects goodness of result, however, seems to depend upon temperature; if this be the same, the results are the same with either form of melting.

69. Usually, however, the temperature of the cupola is vastly higher than that of the air furnace, and its consequence is the formation of an alloy of the bases of the alkaline and earthy metals with the cast-iron, by which its tenacity is always seriously reduced. *These alloys*, when present largely in pig-iron, are always indicated by a peculiar whitish pallor of the fresh fracture, and *are only formed at intense heats, at which also the micaceous plates of uncombined carbon become developed as graphite, upon the largest scale,* a fact first pointed out some years since by Schafhaeutl. Unnecessary heat of fusion then injures the quality of the metal, as unnecessary heat of "pouring" injures the quality of the casting. It does this in two ways, by the introduction of foreign earthy and alkaline bases, which greatly reduce the cohesion, and far more by the great increase of surface produced by extreme elevation of temperature, in the disseminated plates of graphite. These, scattered through the mass like mica or hornblende in granite, present at their innumerable planes of cleavage almost no cohesion; but these planes are, in accordance with the general law of arrangement in the "planes of least pressure," found mainly to coincide in parallelism with those of the crystals of the iron itself (i. e. the carburet of iron which constitutes the metal of cast-iron chiefly), so that the total deterioration of strength due to smelting at an extremely high temperature is very great, and this is in fact the secret of the much discussed and unquestionable inferiority of hot-blast iron over cold; nothing more than the elevated temperature induced in the blas furnace. All cast-iron, in its progress towards wrought-iron in the "puddling" process, passes through an intermediate stage, in which it is more or less perfect cast-steel; and the Styrian steel (Stahleisen) is produced direct from the "finery pig" merely by an adroitly managed puddling, stopped at the proper moment.

70. I shall conclude this portion of the subject by the following Table, principally derived from my Report (Trans. Brit. Ass., 1840), in which the general characteristics and working qualities of the more important "makes" of British cast-iron are combined and systematized :—

Table III.

General Classification *of the principal Makes of British Cast-Irons as applicable to Artillery.*

No.	Class of Iron.	Hot or Cold.	Commercial No.	Fracture.	Character in Working.	Specific Gravity.	How Cast.	Physical Maxima and Minima.
1	Apedale,	Cold.	No. 2.	Silvery.	Least fusible; thickening rapidly when fluid by a spontaneous "puddling;" vesicular, often crystalline, incapable of being cut by chisel or file; ultimate cohesion a maximum; and elastic range generally a minimum.	7·603	Chilled.	
2	Hardest procurable,		Scrap.	"		7·624	Sand.	Maximum density.
3	Oldberry,	Hot.	No. 3.	"		7·501	Sand.	Coefficient E, nearly as in No. 22.
4	Ponkey,	Cold.	No. 3.	"		7·233	Sand.	Maximum ultimate strength and value of T_e, nearly as in No. 40.
5	Peutywn,	Hot.	No. 2.	"		7·629	Chilled.	
6	Calder,	Hot.	No. 4.	"		7·527	Sand.	
7	Shotts,	Hot.	No. 4.	"		7·158	Sand.	
8	Doulais (Finery Pig),	Hot.	No. 4.	"		6·378	Sand.	Full of microscopic vesicles.
9	Arigna,	Cold.	No. 1.	Micaceous.	Very soft; feels greasy; peculiar micaceous appearance, generally owing to excess of manganese; soils the fingers strongly; crystals large; runs very fluid; contraction large.	7·015	Sand.	
10	Burchill's,	Cold.	No. 1.	"		6·928	Sand.	
11	Muirkirk,	Hot.	No. 2.	"		6·980	Sand.	
12	Peutwyn (peculiar),	Hot.	No. 1.	"		7·000	Sand.	
13	Arigna,	Cold.	No. 3.	Mottled.	Tough and hard; can be with difficulty filed or cut; crystals large and small, mixed; sometimes runs thick; contraction on cooling a maximum.	7·308	Chilled.	
14	Apedale (Cylinder Iron),	Hot.	No. 2.	"		7·116	Sand.	
15	Peutwyn,	Hot.	No 2.	"		7·017	Sand.	
16	Calder, No. 1 + Peutwyn, No. 2 + Scrap,	. .	. . . .	"		7·168	Sand.	
17	Gray Cast-Iron (Blaenavon, No. 2 + Scrap),	. .	. . . .	"		7·138	Sand.	Maximum contraction in cooling.
18	Monkland,	Hot.	No. 4.	"		7·294	Sand.	
19	Clyde,	Cold.	No. 1.	"		7·140	Sand.	
20	Parkfield,	Cold.	No. 1.	"		7·248	Sand.	
21	Apedale,	Hot.	No. 1.	"		7·268	Sand.	
22	Devon,	Cold.	No. 3.	"		7·280	Sand.	Coefficient E, maxim. but T_e small.
23	Calder,	Hot.	No. 1.	"		7·079	Chilled.	
24	Arigna ½, Scrap ½,	. .	. . . .	"		7·134	Chilled.	
25	Calder ½, Scrap ½,	. .	. . . .	Bright Gray.	Toughness and hardness most suitable for working; ultimate cohesion and elastic range generally are balanced most advantageously; crystals uniform, very minute.	6·329	Chilled.	Minimum density, porous, as No. 8.
26	Gartsherry,	Hot.	No. 2.	"		7·115	Sand.	
27	Low Moor,	Cold.	No. 2.	"		7·150	Sand.	
28	Shotts,	Hot.	No. 2.	"		7·152	Sand.	
29	Blaina,	Cold.	No. 3.	"		7·159	Sand.	
30	Arigna,	Cold.	No. 3.	"		7·141	Sand.	
31	Gartsherry,	Hot.	No. 1.	"		7·001	Sand.	
32	Shotts,	Hot.	No. 3.	"		7·183	Sand.	
33	Varteg Hill,	Hot.	No. 2.	"		7·074	Sand.	
34	Calder,	Hot.	No. 3.	"		7·064	Sand.	
35	Summerlie,	Hot.	No. 2.	"		7·156	Sand.	
36	Madeley Wood,	Cold.	No. 1.	"		7·115	Sand.	
37	Elsecar,	Cold.	No. 1.	"		7·097	Sand.	
38	Cinderford,	Cold.	No. 1.	"		7·049	Sand.	
39	Carron,	Hot.	No. 2.	"		7·081	Sand.	
40	Gartsherry,	Hot.	No. 3.	"		7·074	Sand.	Value of T_e, maximum.
41	Muirkirk,	Hot.	No. 3.	Dull Gray.	Less tough and hard than the preceding; other characters alike; contraction on cooling generally a minimum.	6·838	Sand.	
42	Monkland,	Hot.	No. 3.	"		7·124	Sand.	
43	Doulais,	Hot.	No. 1.	"		7·164	Sand.	
44	Arigna,	Cold.	No. 2.	"		6·809	Sand.	Minimum density, solid.
45	Shotts,	Hot.	No. 1.	"		7·109	Sand.	
46	Lillieshall,	Cold.	No. 1.	"		7·205	Sand.	
47	Shotts,	Hot.	No. 2.	"		7·152	Sand.	
48	Caedtalon,	Hot.	No. 2.	"		7·030	Sand.	
49	Buffery,	Hot.	No. 1.	"		7·063	Sand.	
50	Caedtalon,	Cold.	No. 2.	"		7·020	Sand.	
51	Carron,	Cold.	No. 2.	Dark Gray.	Most fusible, remains long fluid; exudes graphite in cooling; soils the fingers; crystals large and lamellar; ultimate cohesion a minimum, and elastic range generally a maximum.	7·107	Sand.	
52	Doulais,	Cold.	No. 3.	"		7·159	Sand.	
53	Doulais,	Cold.	No. 1.	"		7·192	Sand.	
54	Blaenavon,	Cold.	No. 1.	"		7·143	Sand.	
55	Muirkirk,	Cold.	No. 2.	"		7·076	Sand.	
56	Milton,	Hot.	No. 1.	"		7·073	Sand.	
57	Calder,	Hot.	. . . .	"		7·027	Sand.	Minimum ultimate strength.
58	Calder ½, Peutwyn ½,	. .	. . . .	"		6·978	Sand.	
59	Arigna ½, Peutwyn ½,	. .	. . . .	"		7·050	Sand.	

Note.—All deduced from equal pieces, cast one inch thick and five inches square.

8.—*Causes of Liability to Bursting in firing Red-hot Shot.*

71. Amongst the causes assigned by artillerists for the frequent bursting of guns in firing red-hot shot, have been these, that the windage is reduced by the expansion of the shot enlarging its great circle, and hence the stress upon the gun increased; and that by the conjoint effect of the heat of the shot, increasing its diameter, and that of the expansion of the gun (produced by the heat of the shot) in an internal direction, or towards the axis, diminishing its caliber, the shot becomes wedged in the gun. That this solution is erroneous is not difficult to prove.

72. Sir H. Douglas (Naval Gunnery, p. 88) states that at a white heat a 24 lb. shot expanded $\frac{1}{70}$; a 16-pounder, $\frac{1}{76}$; and a 6-pounder, $\frac{1}{82}$ of their respective diameters. These figures are probably erroneous, inasmuch as if the coefficient of expansion and the temperature be the same for each shot, the ratio of expansion to diameter should be the same for all.

Professor Daniell's experiments with his own pyrometer gave the lineal expansion of cast-iron between 62° Fahr. and its melting point at $\frac{1}{61}$ part, very nearly; it is almost certain that this largely overrates the amount, as the results of practice in iron-founding have constantly proved that the contraction of fluid cast-iron in becoming solid seldom reaches $\frac{1}{120}$ of the lineal dimensions, and never exceeds $\frac{1}{90}$.

The figures given by Sir H. Douglas, however, may, perhaps, be accounted for in this way—that the three diameters of shot were all cast from different qualities of iron, and that, being cast in iron moulds, a certain amount of internal strain might remain permanently upon them, by the rapidly chilled spherical crust compressing the interior, which is relieved when the shot is again heated red-hot, and which compressive strain would vary with the diameter, and be least for the largest shot. The 6-pounder shot being small, and probably equally hard all through, this would not apply to it.

73. However this may be, it is certain that shot, cast in iron moulds, *must* have a constant strain of the exterior upon the interior, and hence a powerfully increased tendency to split and fly to pieces on striking any hard object, such as a wall; and this suggests that shot intended for battering purposes would

probably with advantage be either cast in sand (like shells), or, if in iron moulds, afterwards annealed. The use of iron moulds, however, appears to be abandoned in several British foundries.

74. Shot frequently heated red-hot are said permanently to enlarge; this needs confirmation, but it would follow as a consequence of the conditions assumed above to account for Sir H. Douglas's figures. The explanation, therefore, would receive some corroboration from this, if established.

75. We may, however, assume the mean diametric expansion of white-hot shot (a temperature never reached in practice) as about $\frac{1}{90}$ the diameter; and the following Table will show the impossibility of shot of the six largest classes of ordnance becoming jammed in the gun from this cause, even assuming a certain amount of internal expansion in the gun itself, which, if it produce diminution of bore at all (as we shall hereafter see reason to doubt), must do so imperceptibly, from the slight degree of heat communicated, and from its effect being divided between compression of the interior and extension of the exterior portions of the whole thickness of the gun:—

Gun.		Diameter of Bore.	Diameter of Shot.	Windage.	Expansion of Shot at white heat.	Remaining Windage for hot shot.
1	10 in.	10·00	9·840	0·160	0·109	0·057
2	8 ,,	8·05	7·922	0·125	0·088	0·037
3	68-pr.	8·12	7·920	0·200	0·088	0·112
4	42 ,,	6·97	6·770	0·200	0·075	0·125
5	32 ,,	6·41	6·177	0·233	0·068	0·165
		6·30	6·177	0·123	0·068	0·055
6	24 ,,	5·72	5·595	0·125	0·062	0·063

Nos. 1 and 2 are shell-guns.

76. Even were we to adopt Sir H. Douglas's coefficient of expansion for the 24-pounder, and apply it to the 32-pounder, the gun having the smallest windage of any in the Table, the shot would still have 0·0348 of windage left; and, as the values of a in the empirical formula frequently used for obtaining the velocity of shot—

$$V = 1600 \sqrt{\frac{ac}{w'}}$$

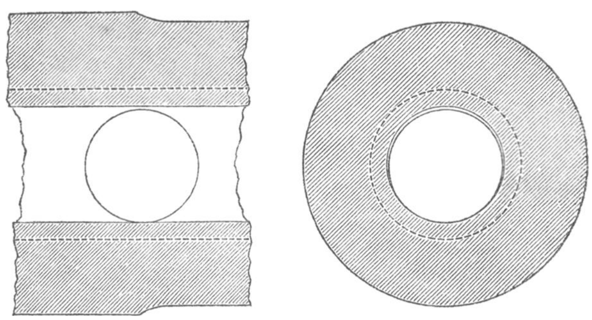
in which c is the weight of the powder, and w' that of the shot, a a coefficient, having the following values for different windages:—

Windage.	Value of a
0·233	= 3·2
0·200	= 3·4
0·175	= 3·6
0·125	= 4·4
0·090	= 5·0

shows that its value only varies from 5·0 to 3·2 for the extreme range of windage from minimum to maximum; so neither can the increase of strain on the gun due merely to diminished windage be the true cause of frequent bursting in firing heated shot.

9.—*Nature and Effects of Local Expansion by Heat on Guns.*

77. What, then, *is* the cause? I conceive it may be proved to be *the enormous strain produced locally upon the exterior portions of the metal of the gun in the neighbourhood of the charge, by the expansion of the interior of the chase or bore due to the rapid communication of heat from the shot* suddenly lodged within the gun bringing its external circumference at the place into a violent state of tension, in which state the gun is directly exposed to the further, suddenly applied and jarring strain of the discharge.



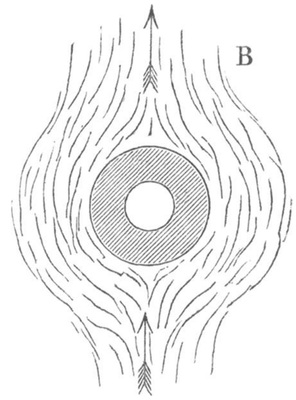
78. The diagram may represent in longitudinal and in transverse section a portion of the bore of a gun with a red-hot shot lodged within it preparatory

to being fired. The shot *lies* in contact with the *lower* side of the chase, and so heats the adjacent portions of metal of the gun, by direct contact, conduction, and radiation; at every other point round the interior circumference of the chase it is separated by a lunaric interval due to the windage, which is widest at the upper side of the shot. All round this the interior surface of the gun is heated almost wholly by radiation from the hot shot. The heat thus communicated to the gun at its interior surface travels slowly, in pulses, outwards through its metal, and is still more slowly carried off and dissipated in the surrounding air from its exterior. It also moves in pulses by conduction through the metal, in the direction of the length of the gun; but the main volume of heat communicated to the gun is accumulated closely in the neighbourhood of the shot when rammed home. Each heated shot in succession adds some increment of heat to that already acquired by this part, provided the interval between one discharge and the next be not sufficient to enable the gun to cool down to its former temperature, which can scarcely happen in service, or unless it be cooled artificially. The gun is also heated powerfully in the whole length of its interior by the flame of the powder, but the heat due to this also produces its greatest effect close to the seat of the cartridge and shot when rammed home.

79. The result is, that in continued firing (whether with cold or hot shot) the interior of the gun is hotter than the outside, and that the parts of the gun nearest the breech are the hottest, and that the point around the interior circumference here, which is the hottest of all, is the lowest point; and furthermore, that when red-hot shot are fired, all the conditions are greatly exaggerated under which heat is communicated to the interior. Now heat is dissipated from the exterior in two ways—by *radiation*, which, although not always strictly equal all round, may be assumed commonly to be so, and by *evection;* that is to say, by currents of air, which may act in either of two directions, vertically or horizontally, but which generally act together. Lateral or longitudinal currents due to wind carry off a portion proportionate to the low temperature and velocity of the air in motion.

80. Vertical and ascending currents are at the same time produced by the rarefaction of the air immediately in contact with or adjacent to the heated gun (which we assume to be nearly horizontal). These ascend, and give place to fresh portions of colder air, which, impinging first upon the lowermost side of the

gun, creep up past both its flanks, traverse more or less over its upper surface, and meeting, pass away. The diagram B illustrates this.



B

81. The conjoint action both of wind and of these ascending currents will be to inflect the otherwise vertical upward movement of the latter more or less diagonally, but the conjoint action may produce more rapid cooling than that of either separately. The ascending currents of air, like those of the wind, evect heat proportioned to the low temperature of the air and their velocity of ascent. The latter is greatest at the points of the gun that are hottest; the velocity of the wind being the same for every part of its length.

82. The result as to cooling, therefore, is, that in moderately still air the lower side of the gun, upon which the cold air first strikes, is cooled fastest, and its top side slowest. The same is the case with a wind blowing in a line with the axis of the gun; but with a side wind the gun will be cooled fastest along a line of its exterior, somewhere between its sections by a vertical and by a horizontal plane, both passing through the axis, and will remain hottest along the side diametrically opposite.

83. The shot and gun being both iron, every degree of sensible heat, lost by the former, will communicate a degree of sensible heat to the latter; but the *heat* lost is diffused through a larger mass, and hence conveys a diminished sense of *warmth.* We have no means of determining, in the absence of experiments, either the heat taken up by the gun, under given conditions in a given time, or the actual velocity of its transmission through the metal forming the thickness of the gun, from its interior surface.

84. But we are enabled to show, that at whatever rate the interior surface of the gun may be heated, the passage outwards of the heat through its mass will be so slow and retarded that the interior must be always greatly hotter than the exterior. The case is one of conduction, and may be viewed, without material error, as analogous to that of a uniform metallic bar, heated at one end, the bar being assumed as any elementary radial portion of the gun's thickness.

85. Biot (Traite de Phys.) has shown that if the extremity of such a bar be maintained at a temperature $= (y) + Y$; y being that of the bar originally and

of the air surrounding it, and Y that of the focus of heat, and x any abscissa whose origin is in Y, then the integral of the differential equation

$$\frac{dy}{dt} = a\,\frac{d^2y}{dx^2} - by$$

which determines the momentary variation of y (a and b being constants, and $y + (y)$ the temperature of the bar at the time t) becomes, on certain assumptions—

$$y = Y \times (10)^{-\frac{x}{M}\sqrt{\frac{b}{a}}}$$

whence

$$\text{Log}\, y = \text{Log}\, Y - \frac{x}{M}\sqrt{\frac{b}{a}}$$

M being the modulus of the common logarithms. Applying this formula to the results of experiment with a bar heated at one end, and furnished with eight thermometers, at the distances apart given beneath, he found the following temperatures for the several points along the bar:—

Number of Thermometer.	Distance from Y.	Corresponding Temperature.
0	0·00	68·48
1	2·11	23·50
2	3·11	14·16
3	4·00	9·00
4	4·97	5·55
5	5·90	3·45
6	7·77	1·33
7	9·67	0·51
8	11·55	Insensible.
End of Bar.	27·34	,,

In which experiment and calculation were found to square closely. The figures in the third column show clearly the enormous difference in temperature between the two ends of the bar, freely conducting heat.

Biot's general differential equation does not precisely apply to the case of a gun whose metal is heated from the interior and cooled from the exterior only, being much the same as a bar (or elementary radial section of the metal of the gun) heated at one end and *cooled at the other only*, and to which conditions the

latter member of the equation only would apply. In the absence, however, of any knowledge of the constants that would admit of an exact expression for the phenomena before us, Biot's may serve as an illustration of the enormous disproportion in temperature between the interior and exterior of the gun.

86. But a more precise expression for the facts may be had. M. Weidemann, in a recent Memoir on the Transmission of Heat in Metals (Poggen. Annal., St. 95, p. 337), has found experimentally that a bar of zinc, having thermometers placed at distances of two inches apart along its length, and heated constantly at one end to 100°, had the following temperatures at each of the thermometric points, viz.:—

Length of Bar in inches from Focus of Heat.	Corresponding Temperature.
0 inches.	100°·0
2 "	57 ·0
4 "	33 ·1
6 "	20 ·0
8 "	12 ·0
10 "	7 ·2

Now these results, obtained experimentally for zinc, are to a near approximation true for iron (and probably for *cast*-iron), as the *relative* conducting powers for heat of zinc and iron are as the numbers 363 and 374 (Daniell, Chem. Phil. p. 121). We may, therefore, conclude that a cast-iron gun, whose thickness is 10 inches, and whose interior is heated to 100°, will lose heat from its exterior, at the rate due about to the temperature of 7·2°.

87. These conclusions, though not strictly correct, are sufficient to indicate the enormous disproportion in temperature that must subsist between the interior and the exterior, and that is all we are at present concerned with.

Experimental data are as yet wanting, to enable this question to be pursued with exactitude. It is necessary first to learn experimentally what is the extreme of temperature acquired by the interior of each class of gun, over that of its exterior, in firing hot shot; and the *actual rate in time* at which the wave of heat travels outwards *by conduction only* through the substance of the gun, a constant as yet unknown for any substance.

Were these data known, a formula could be obtained by which the total effect may be expressed of the splitting strain, produced by the mechanical effort of the expanded interior, upon the relatively cold and unexpanded exterior of the gun,—a force variable in the direction of the radius, and which is a maximum at the interior surface, and zero or a minimum at the exterior one, or at a point somewhat within it.

10.—*Mechanical Equivalent of Expansion by Heat.*

88. The measure of the mechanical equivalent of heat employed in producing dilatation or contraction in a solid, may be expressed in tons by the equation,

$$F = \frac{T - t}{c} \tag{3}$$

in which T is the higher, and t the lower temperature, and c a constant representing the number of thermometrical degrees that the given solid must be heated or cooled to produce an elongation or a contraction equal to that which it would undergo by a tensile strain, or a compressive force of one ton, upon the unit of surface. This equation assumes the body absolutely hard, and its elasticity perfect, and hence is not absolutely true for any known substance. All ductile metals, when heated or cooled under the constraint of resisting forces, appear slowly to change their forms, and so accommodate themselves without rupture or disunion to a strain, which, were they perfectly rigid, we shall see presently, must in many practical instances otherwise far surpass the total cohesion of the material. Thus, for example, the wrought-iron tires of railway carriage-wheels are "shrunk" on red hot upon the bodies of the wheels, and either cooled instantly in water, or permitted to cool slowly. In either way it may be shown that the force developed by the contraction from a red heat to the temperature of the atmosphere (60°), must inevitably, and in every case, rupture the metal of the tire band, because the amount of contraction would far exceed the total extension due to rupture of the iron. It does not do so, however, unless in exceptional instances, arising from defective workmanship or material; and the reason is, that through the ductility of the iron, especially at a high temperature, it yields to the force, and draws out in length slowly, as it cools, until the elastic forces assume a new state of equilibrium, and with the

residual force of which the tire grips the wheel. A length of time probably elapses before this state becomes perfectly stable, and indeed the gradual loosening of tires, though partly due to the extension of the iron under the continued rolling out which it sustains against the rails in use, makes it somewhat doubtful if stable equilibrium be ever attained.

89. Assuming, however, the rigidity of the metal perfect, which is in fact extremely great in cast-iron, then in a cylinder, such as a gun, exposed to expansion in the inside, the strains are the same as if it were exposed to the normal and tangential strains due to a fluid pressure from within, and as (eq. 1) the equation for equilibrium is—

$$p = R\frac{(D - D')}{D'} = \frac{2\,Re}{D'}, \tag{4}$$

when

$$\frac{T - t}{c} = \frac{2\,Re}{D'}, \tag{5}$$

the gun would be burst by the expansion of the interior alone; or if the former be less than the latter member of the equation in the ratio of $\frac{e}{n}$ then is the n^{th} part of the whole strength of the gun temporarily removed by its internal expansion, or by the reaction of the interior, against the exterior segment of its thickness.

Applying Professor Hodgkinson's experimental results as to the extensibility of cast-iron under strain, to this reasoning, and taking the coefficient of expansion by heat, for cast and wrought-iron as the same for low temperatures (strictly as 1000893 : 1000984 for temperatures under 212°), we have the extension for cast-iron for the square inch of section equal about $\frac{1}{5000}$ of its length for each ton of load, up to 7 or 8 tons, at which its elasticity becomes permanently impaired, that is to say, when it begins to lose its form. An equal change of length is due to eight degrees of Fahr., difference in temperature. (Note K).

11.—*Numerical Example.*

90. Let us now assume a 64 lb. shot, rammed home at 2000° Fahr., which is under a white heat, and that it remains fifty seconds in the gun while the latter is being run out and fired; that in this interval the shot transmits $\frac{1}{10}$ of its

heat to an equal mass of the cold gun; and that the whole of this is operative in expanding a cylindric ring of a determinate thickness around the ball :—then, we have

$$F = \frac{200^\circ}{8^\circ} = 25 \text{ tons},$$

as the mean compressive strain per square inch upon this interior ring. But as the ultimate cohesion of cast-iron does not exceed about 8 tons to the square inch, the actual effect upon the strength of the gun is the same, as if about three inches of its thickness were removed, or that an inch in thickness of its interior metal were removed, and a total strain of 17 tons were at the same time visited upon the remaining section of its thickness. At such a conjuncture, with such a steady strain already on its metal, the gun is fired, and an additional impulsive strain, equal to the work done in giving to the shot its initial velocity, is suddenly brought upon its material.

This, even with the regulation reduced charge for hot shot, of $\frac{3}{4}$ the service charge for cold shot, is seldom less than $2\frac{1}{2}$ tons on the square inch of section, producing, from the impulsive nature of the force, an extension equal to that of a passive strain of 5 tons. The wonder, then, is rather that any gun stands, than that many should burst.

91. Nor does this statement fully embrace the entire strains visited on cannon by expansion. It is uncertain whether the coefficients of expansion for cast-iron in three rectangular axes are alike. There seems good reason to suppose that iron is a dimorphous body, and that in its rhombohedral form at least they are not so. Its unequal expansion, then, in different directions, probably introduces torsional strains, as well as the normal and tangential ones which we have so far alone considered. We have neglected altogether the longitudinal ones, and this may be safely done, since the pressure required to produce longitudinal rupture is proportionate to

$$P = R\frac{(D^2 - D'^2)}{D'^2}, \tag{6}$$

and that to produce tangential rupture, to

$$R\frac{(D - D')}{D'}, \tag{7}$$

and hence the longitudinal strength of a gun is always greatly in excess.

12.—*Effect of a Heated Gun on the Charge.*

92. To this should be added the consideration, that the ignition of the powder dried by the neighbourhood of the hot shot and in a warmed gun, is probably much more rapid, and its effect on the gun more severe, than in ordinary cases, from causes already and to be again adverted to.

13.—*Phenomena induced in "Quick Firing;" Limit of Heating.*

93. A train of effects, quite analogous to those described, are brought into operation in *very quick firing*, whether with hot or cold shot,—when the interior of the gun, continually receiving fresh accessions of heat from the rapidly succeeding flashes of powder, is not given time, to transmit it by conduction, through its metal to the exterior. The limit of the heat that could be conceived communicated from one discharge to the gun, would be the whole of that generated by the ignition of the charge. Assuming the formula for gunpowder to be $KO, NO_5 + S + C_3$, its atomic weight will be 135, and one part by weight will include 0·1333 of carbon. Now, Andrews (Reports, Brit. Assoc. 1849) found that one part of carbon evolves as much heat in burning as will raise an equal weight of water 7900° Cent. Hence, neglecting the sulphur as not oxidized in combustion, the heat generated by the firing of any charge of powder is sufficient to raise the temperature of an equal weight of water $7900° \times 0{\cdot}1333 = 1053°$ Cent. $= 1895{\cdot}4$ Fahr., or to boil about nine times its own weight of water, or to heat about nineteen times (18·945 strictly) its weight, 100° Fahr.

94. The specific heat of water being unity, that of cast-iron (the mean of those given for iron, 0·125 to 0·143) is probably 0·134 ; and that of gun-metal is 0·11 (Thompson), 0·086 (Regnault). Hence, if C be the weight of the charge of powder, $141{\cdot}4\ C$ is the weight of cast-iron, and $172{\cdot}3\ C$ that of gun-metal that the whole of its heat would heat 100°. If W, therefore, be the weight of the gun, and the heat were uniformly diffused in its mass, $\frac{141{\cdot}4\ C}{k\,W}\ 100°$ will be the resulting temperature in the case of a cast-iron gun, and $\frac{172{\cdot}3\ C}{k\,W}\ 100°$ that for one of gun-metal, k being a constant representing the fraction of the

total heat generated, that is, communicated to the gun in the discharge. Its value can only be determined by experiment, and in continued firing, will decrease at each successive discharge, the gun gaining *less* heat as it becomes warmer from each flash. A medium 12-pounder field-gun weighs 18 cwt., and the service charge is 4 lbs. $= \frac{1}{504}$ of the weight of the gun. If the whole of the heat from one discharge were absorbed by the gun, its temperature, assumed uniform, would be raised about 34° Fahr. The whole heat, however, is not absorbed, nor is that which is retained by the gun uniformly diffused.

14.—*Explanation of "Drooping at the Muzzle."*

95. In this case (that of heating by quick firing) the interior expansion is not almost limited, as in the former, to a ring in the immediate neighbourhood of the shot, but extends to the whole length of the chase or bore, so that the whole gun becomes lengthened by the "end on" strain of its expanded interior. In bronze guns the coefficient of expansion is so great (greater than that of cast-iron in about the ratio of 20 to 11), and the resilience, or power of elastic recovery of form, so small, that in extreme cases the extension due to the end on strain surpasses the elastic limit of recovery, and the gun becomes permanently lengthened. When in this state the firing is continued, and the metal becomes much heated throughout (though still hottest in the inside), heat is carried off by *convection* from the lower side of the gun, by the ascending currents of the air around it,so fast, that the *upper side of the gun is relatively heated and expanded more than the lower side ; and when the cross strain thus produced has bent the metal beyond the limit of its elastic recovery, the gun "droops at the muzzle,"* as it is called, an effect vulgarly ascribed, and even by writers on artillery, to the "softening of the metal by the heat," a condition that could not happen until a temperature should have been attained, at which no cartridge could be placed in the gun without its instantly exploding; in fact, more than a "red heat," 1800° Fahr. (Daniell.)

I am not aware that this explanation of the cause of drooping at the muzzle has been before given. It sufficiently indicates the severity and injudiciousness of the proof test, by "quick firing," formerly applied to all field-guns, and still said to be used by some foreign governments.

Plate IV.

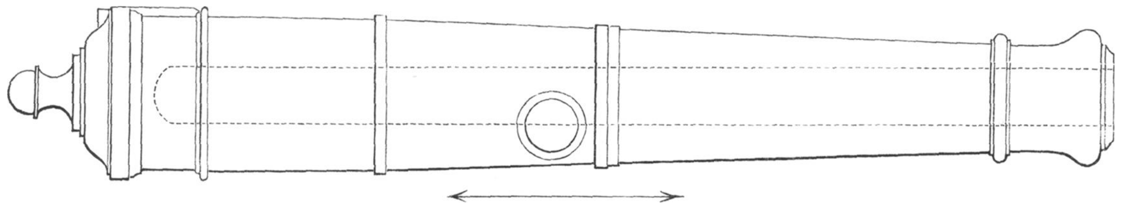


Fig. 1.

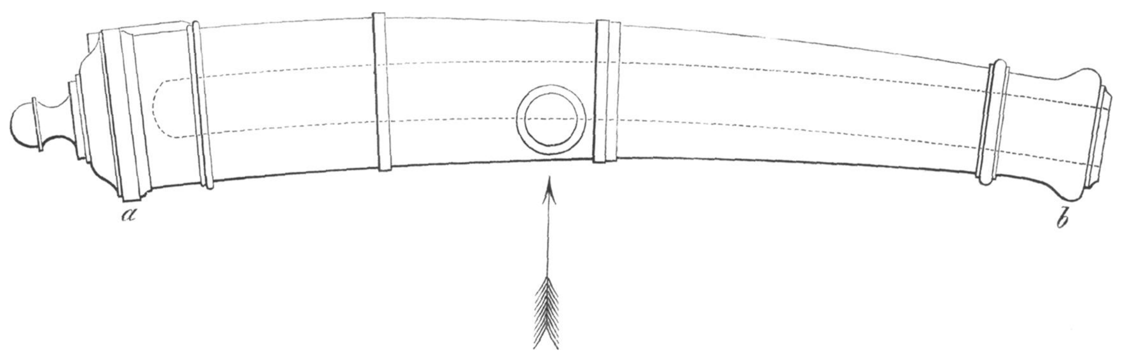


Fig. 2.

Drooping at the Muzzle in Bronze Guns.

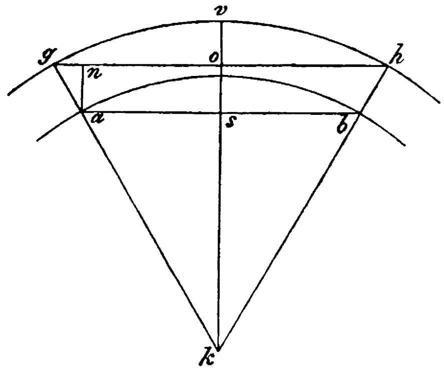
96. The plate No. 4 illustrates this effect on brass guns. Fig. 1 shows a 12-pounder gun fit for service. Fig. 2, the same gun "drooped at the muzzle," in an exaggerated degree. The gun becomes bent on precisely the same principle that the length of the "gridiron pendulum" is preserved invariable, or the bar of zinc and brass in parallel bands of Doctor Ure's "thermostad" is inflected, namely, by the *difference of expansion*, in these latter cases, of two metals having the same temperature, but different coefficients of expansion, in that of the gun by the bar or portion of the cylinder of the same metal, heated to different temperatures at opposite sides of its axis, and, therefore, differently expanded. In a gun whose weight is supported as usual altogether by its trunnions, its own weight acts in favour of the distorting action of this expansion, by the overhanging mass of the breech and muzzle (a fact which, no doubt, led to the popular view of *drooping* at the muzzle); but the same effect, and very nearly to the full extent, would take place if the gun were supported at the two ends, *a* and *b*, Fig. 2, in place of on the trunnions, in which case, in place of drooping, the centre parts of the gun would rise and become arched or hogged, an example that would afford an *experimentum crucis* as to the views here announced.

97. If Δ be the total deflection, and δ that due to local inequality of temperature, and ϕ the experimental flexure of the material for the unit of length and diameter, then $\Delta = \delta + \frac{12}{1} \frac{l^3 W}{\phi D^3}$ when the gun rests upon the trunnions, and $\Delta = \delta - \frac{5}{8} \frac{2l^3 W}{\phi D^3}$ when the gun is supported at both ends only, assuming the general form cylindrical, and neglecting the comparatively small portion removed by the bore.

98. From statements further back, as to the variable temperature of points taken from the inside towards the outside of the thickness of the gun, it will be seen that we are not able at present to determine at what distance from the axis, in a vertical diameter passing through it, we might consider the whole of the opposing forces tending to bend the gun concentrated; were we able to fix these centres of effort for any particular gun, the extent of its distortion for a given difference of temperature between the upper and lower sides might be calculated. It is probable that in guns of the usual proportions of heavy bronze guns,

these centres of effort will be distant about one caliber fromeach other. The lineal expansion of cast-iron for 150° of heat is = ·000893, and that of gun-metal probably = ·001541, the length originally being 1·000000 (Daniell).

The total elongation, therefore, for a gun of nine feet in length of chase, due to a rise of temperature of 300°, would, if of gun-metal, be = ·0332856 inches, say ·034 inches.



99. We may readily approximate to the curvature that will be produced in any case.

For let ab = the length of the colder and shorter side of the gun ;

gh = that of the hotter and longer side, both taken at the assumed centres of effort ;

os = the distance between these perpendicular to the axis of the gun ;

and assume the gun to bend into a segment of a circle, of which $gvh = A$ is an arc, k the centre, and kg a radius; then, calling $\frac{ab}{2} = l$, and half the difference between ab and gh = half the elongation $= e$; and let $os = c$, then we can find gk and $gk - i = R$, the radius, and vo = the versed sine of curvature ; for, calling the side ga of the small right-angled triangle $gna = i$, we have

$$i = \sqrt{(c^2 + e^2)}\ ;$$

but

$$i : e :: R + i : e + l,$$

$$\therefore R + i = \frac{\sqrt{c^2 + e^2} \times (e + l)}{e}.$$

Again, in the triangle gko,

$$\sqrt{(R + i)^2 - (l + e)^2} = ok,$$

and

$$(R + i) - ok = ver\text{-}sin\ A. \qquad (8)$$

15.—*Numerical Example.*

100. If we apply this to a 32-pounder brass gun, of 9 feet in length, in which—

$$l = 54 \text{ inches,}$$
$$c = 6{\cdot}5 \text{ inches nearly; and}$$
$$e = {\cdot}017 \text{ inches,}$$

we shall find that with the difference in temperature of 300° between the two opposite sides, the radius of curvature will be $267\frac{1}{6}$ feet, and the versed sine, 0·46 inches, that is to say, the gun will be bent nearly half an inch from a straight line.

The cause assigned is sufficient, therefore, to account for the extent of the phenomena.

16.—*Relation as to Distortion, of Gun-Metal and of Iron Guns.*

101. It may be questioned, then, why does "drooping at the muzzle" occur in gun-metal guns, and never in cast-iron guns. It *does* occur in cast-iron guns, but in a degree so much diminished, as to be in them, imperceptible; and, furthermore, after cooling again to an uniform temperature, the cast-iron gun will, under all practical conditions (as to the extent to which it can be heated unequally), recover its form, which the gun-metal one may not.

The following are the chief reasons, however, why this distortion is so much greater in guns of gun-metal than of cast-iron of equal sizes, forms, and charges:—

1°. The gun-metal is *much more heated* by each discharge, in the ratio by which it is a better conductor of heat than cast-iron, or as about 89 : 37, and, therefore, takes up more heat during the moment of the flash. This is modified also in the inverse proportion to their respective specific heats, so that the same quantity of heat that would raise the temperature of the cast-iron gun 110° will raise that of the gun-metal gun 134°. The gun-metal gun, therefore, takes up from each discharge, of the same weight of gunpowder, about three times as much heat as the cast-iron gun.

2°. Gun-metal is much more ductile and less elastic than cast-iron, and possesses a much longer range through which its form may be altered, before its elasticity is finally overcome, though with a

greater cohesive force than cast-iron ; in fact, the element of extension, upon which the value of T_e the coefficient which M. Poncelet denominates " de la resistance vive d'elasticité," or the "modulus of resilience" of other writers, referred to hereafter, depends, is much greater for gun-metal, and hence a given force produces a greater proportional distortion of form.

3°. As already remarked, the gun-metal has a coefficient of expansion, by equal heat, far beyond cast-iron, or as 1541 : 893, or nearly as 15½ to 9. Hence, equal inequalities of temperature will produce nearly double the distortion in the gun-metal.

4°. A very moderate increase of temperature above that of the atmosphere (say 50°) greatly reduces the cohesion (and probably in a far higher ratio the stiffness) of gun-metal, as the researches of Baudrimont have rendered nearly certain, while it produces a directly opposite effect on iron, and, we may conclude, on cast-iron.

102. Baudrimont has ascertained that the relative cohesive powers (coefficient of rupture) of copper and of iron at the three temperatures, 0°, 100°, and 200° Cent., are in the ratios of the following numbers,* which, as respects both, agree pretty well with the results of the experiments of the Franklin Institute :—

	TEMPERATURE.		
	0°	100°	200°
Copper, .	25338	22050	19839
Iron, . .	205405	191725	210270

If, therefore, gun-metal and cast-iron follow the same law, as it can scarcely be doubted they do, a gun-metal gun heated from the freezing point of water to 200° Cent., loses resisting power in the ratio of about 20 : 25⅓, while a cast-iron gun gains resisting power in the ratio of about 21 : 20½, having, however, an intermediate weak point at 100°, where its resistance diminishes to nearly 19, a fact which indicates that cast-iron guns are safer *in this respect* when strongly heated, than when heated less.

5°. The rough black surface of a cast-iron gun enables it (on principles

* Ann. de C. T. xxx. p. 304, and Pogg. Annal., LXXXII. p. 156.

discovered by Leslie) to cool faster than a smooth gun-metal gun, with a semi-bronzed and polished surface, so far as *radiation* alone is concerned, which, being equal all round the gun, tends to make it, so far, cool equably, but the heat is carried off by evection faster from the surface of the gun-metal, in consequence of its higher conducting power, and it is the evected heat (lost chiefly from the lower side of the gun, as has been already shown) that produces the main *inequality* of temperature in the piece; the disadvantage, therefore, is all on the side of the gun-metal.

103. Pursuing the method of Dulong and Petit, and of Regnault, for determining specific heats, equal masses in cooling, under like conditions, lose quantities of heat proportional to

$$\Sigma \, (T-t) \times \sigma P. \tag{9}$$

Σ being the specific heat; σ, the specific gravity; T and t, the temperatures of the body and the medium; and P the volume in each case.

If $T-t$ be the same for each of two different bodies, with the same volume and form, &c., equal cooling shall, under similar conditions, occur in times proportionate to

$$\Sigma \times \sigma P,$$

or in equal times the heat lost will be in the same proportion.

This for gun-metal and cast-iron will be,

Gun-metal,	. .	$0{\cdot}110 \times 8400 = 924,$
Cast-iron,	. .	$0{\cdot}134 \times 7500 = 1005.$

The gun-metal cooling, so far as its specific heat and density alone are concerned, rather the more slowly.

104. But from the recent experiments of Prevostaye and Desaines, the relative radiating power of rough cast-iron, painted black, to imperfectly polished and weather bronzed gun-metal, may be assumed as 90 : 15.

Combining, then, the three principal elements in each case, for equal and similar volumes at equal temperatures, and in the same media of equal temperatures, we have the relative rates of cooling for gun-metal and for cast-iron in the following ratio:—

	Σ	r	C
Gun-metal, . .	$924 \times$	$15 \times$	898,
Cast-iron, . .	$1005 \times$	$90 \times$	374.

or, as

$$124{\cdot}46 : 338{\cdot}28.$$

105. *The cast-iron gun of the same size and in the same conditions will cool, therefore, nearly three times as fast as the gun-metal one, taking no regard to the heat lost in both cases by evection.*

106. 6°. The softness and flexibity of gun-metal, as compared with cast-iron, enables its form in guns to be distorted partially by internal forces locally applied, which in cast-iron, are diffused in virtue of its stiffness, through the other parts of the mass, and which thus cause the whole to yield (if at all) without alteration in form, or unsymmetrically.

M. Ardent, of the French Corps de Genie, has shown also that in bodies possessing the physical properties of bronze or gun-metal, when elongation due to any tractile force shall have nearly reached the maximum, consistent with immediately unimpaired elasticity, very slight additions of force are sufficient to produce greatly increased elongations; the cohesive forces are no longer in a state of stable equilibrium. When, therefore, a gun is strained by unequal expansion up to a given point, very slight additional strains suffice to destroy its form completely.

Thus it will be perceived that, as compared with those of gun-metal, cast-iron guns possess properties giving a minimum distortion by unequal heating, and the power of complete *recovery* from the small distortion that they do sustain, which is scarcely ever possible in gun-metal, owing to the great range indicated by its coefficient T_e.

107. The great extent of local distortion to which heavy brass ordnance is liable is instructively shown by observation of the state of the upper side, at the muzzle, of the chase of the French howitzer in St. James's Park: where the shells appear to have grazed hardest, on leaving the gun, all projectiles (as is well known) being thrown from side to side on passing through the chase, by the play of windage (*ballottage*). The inner arris of the muzzle in this case is quite beaten out, and elevated in an angular ridge above the level of the flat terminal of the

remainder of the muzzle. But while the extreme rigidity and high elasticity of cast-iron guns, are thus valuable and important, these properties, coupled with the crystalline structure and low coefficient of rupture of cast-iron, carry with them a train of disadvantages.

17.—*Effects of Rigidity and repeated Discharge in Iron Guns—Limit to the Number of Rounds.*

108. The rigidity of the iron gun, greater in proportion as the metal is whiter and harder, is such that partial distorting forces transfer themselves, to a great extent, to the whole mass. The expansion of the interior of the gun, acting tangentially, exercises against its rigidly resisting exterior, a powerful splitting strain. The elongation of the interior of the chase, from the same cause, drags or forces the exterior, to elongate along with it. The condensation by repeated rounds, straining the metal of the interior beyond its elastic limit, is rapidly propagated at every pulse to the exterior "couches" of material, and hence gradually diminished resistance. The crystals forming the mass are at each blow shaken more and more from perfect contiguity or contact, and from their respective positions of molecular equilibrium, the particles of the whole mass are loosened, and after a number of rounds greater or less, the gun finally fails with a charge perhaps far below that of the proof, which it has many times before withstood.

Such a result is unknown, or rather impossible, with gun-metal guns, unless unequally overheated, or overloaded, and simply because of their long range of elastic yielding, the high value of T_e, that is, of the "work done" to stretch the material to any given extent. To use a popular illustration,—the molecular properties of gun-metal in resisting active forces are of the same character as those which are exhibited (in their extreme limits) by the flexibility and elasticity of caoutchouc, combined with the plasticity of tempered clay; while those of cast-iron are represented in their extreme limits, by the almost perfect elasticity, rigidity, and cohesion of glass, or of various amorphous or crystallized minerals—quartz, for example.

109. In the experiments made by Mr. Hodgkinson, for the Royal Commission, on iron structures, it was ascertained that no cast-iron bar would sustain,

without fracture, 4000 blows, each causing a deflection of one half the ultimate deflection due to rupture from dead weight; but no bar was broken by 4000 blows each producing a deflection of one-third this ultimate deflection: the blow in every case being made with a very moderate velocity.

110. As the value of i, for impulsive forces (Eq. 17, 18) is double that for static pressure, it follows from the above that no cast-iron gun, whose proportions are such that the mean extension of its metal, due to the maximum mean pressure per square inch, of the explosion, exceeds one-fourth the extension due to the strain of static rupture of the material, can withstand 4000 discharges.

111. In the experiments made of a similar character on wrought-iron, however, such a limit for fracture was not reached. We may conclude, therefore, that the number of rounds capable of being fired without final dislocation, from guns similarly proportioned as to ultimate strength in relation to the effects of the charge, will be much larger in wrought-iron than in cast-iron guns;—assuming, however, that in large wrought-iron guns, the physical properties of the wrought-iron are the same as those of small rolled or forged bars, which is far from being the fact, if they be forged in large masses.

112. In the Great Exhibition of 1851 were several cast-iron guns, produced at the Liege Foundry, Belgium, which were certified to have withstood the following number of rounds respectively:—

Size.	Weight, lbs.	Rounds.
30-pounder,	6055	2000
24-pounder, short,	1985	3649
6-pounder,	1954	6002
6-inch howitzer,	1147	2118

Several of the siege guns, 24-pounders, used at St. Sebastian in 1813, are stated to have been fired 6000 rounds; long before which, however, the vents had been burnt away, and replaced, extemporaneously, with brass melted into them.

The mere statement, however, that a particular gun, or one of a particular metal or casting, has stood a given number of rounds, proves nothing as to the superiority or otherwise of the material, for the number of rounds that a gun will stand is dependent, for guns of similar form and proportions, upon—

1°. The coefficients T_e and T_r of the material.

2°. The *excess* of absolute *spare* strength of the gun measured in terms

of these coefficients, above the maximum strain that it is exposed to in discharge; that is to say, upon the small amount of extension of its material at every round.

3°. Upon the uniformity of its molecular arrangement, precluding excessive local strains and extensions (which determine the final destruction of the gun at this, as the weakest point), and upon the absence of "planes of weakness."

4°. Upon the coefficient of velocity for force transmission, for the material.

In every case assuming no injury done by overstraining in any discharge, or by local overheating.

Hence all absolute comparisons which neglect to take into account these several conditions are fallacious, and founded on an incomplete conception of the question.

113. And from these properties it is perhaps chiefly that such capricious uncertainty exists as to the number of rounds that a cast-iron gun will bear before being disabled. Two guns, cast from the same metal, by the same founder, apparently equal in all dimensions, of the same age, both unused, except as to having stood proof, and taken from the same tier in the arsenal, when brought into service with ordinary charges, the one shall stand perhaps 2000 rounds without observable injury, and the other burst after one-tenth, or less, of the number. How do they differ? Not in mere ultimate cohesion; a piece cut from either may sustain almost exactly the same passive load before fracture: but the value of T_e largely differs in one and in the other. The one has its crystalline particles so arranged, and their constitution such, that *a long range of change of form* must be passed through, before rupture is possible. The other has its crystalline arrangement such, that it is rigid, harsh, and unyielding, though not less tenacious, than the former, because it will require as great a force to break it; but it suffers more by every shock, and is sooner, so to say, shaken to pieces. And hence it is, that in our arsenals and gun-foundries, the attention of those in authority, has been and is, so much misdirected, in seeking only for materials for ordnance of the greatest ultimate cohesion, and apparently remaining ignorant of this other equally important, though less obvious or easily grasped condition. It is not a little remarkable that of the three foundries

from which for a length of time the most reliable guns (of cast-iron) in the British service have been produced—viz., the Carron, the Low Moor, and the Gospel Oak Works, are those whose "makes" of iron present precisely the character here insisted upon—namely, an extremely high coefficient of extension (T_e) as compared with their absolute ultimate resistance to rupture.

Having in the foregoing pages pointed out some of the circumstances, almost all of a character purely physical, i. e., molecular, which affect both the construction, and the destruction of ordnance, I propose to discuss briefly the relative advantages and disadvantages of the same class, which belong to each of the four principal materials that have been in use, or are now proposed for their fabrication. These are, gun-metal, cast-iron, wrought-iron, and steel.

18.—*The General Relations of Elasticity to the Construction of Guns.*

114. The elasticity of solids is of two sorts—*cubic elasticity*, which is the resistance that the body presents to change of *volume* by the application of pressure; and *linear elasticity*, which is that which opposes change of *form*. These are very different in different bodies, and different from each other in the same body.

Glass or steel, for example, powerfully resists either change of volume or of form; caoutchouc admits of a large alteration of either. Cork readily changes its form; its lineal elasticity is great, while its cubic elasticity is small: while cold carpenter's glue or whalebone probably present to it, relations exactly the reverse.

When change of form takes place in a solid, whether by extension or compression, it is always accompanied by some change of volume; otherwise the heat evolved on rapid and considerable change of form (as in tearing asunder a bar of iron) is hard to be accounted for. The specific heat diminishing as the density increases, by decrease of volume, at or near the point of rupture; or possibly the heat evolved being the mechanical equivalent of the force employed in producing the changes in volume. It cannot be that, of the force employed in producing change *of form only*—because mere fracture, as when a hole is struck out from a thick plate of iron by a cannon shot (under whose rapid stroke the toughest iron breaks as a brittle body), produces a remarkable rise of temperature in the adjacent parts of the plate.

115. Poisson has shown, and Cagniard de la Tour has experimentally verified, a singular relation between linear and cubic extension or compression; that if $i = \frac{l}{L}$ be the proportional elongation of a bar whose length is L, and whose elongation for unit of length is l, and a the diminution of cross section, which the original cross section A sustains as due to i, then

$$\frac{a}{A} = \tfrac{1}{2}i = \frac{l}{2L} \tag{10}$$

so that the reduction of cross section is equal to half the elongation. From which it follows that the total volume of the bar *augments* by a fraction $= \frac{1}{2}i$, although its cross section diminishes. The original volume of the bar $= AL$ becomes

$$(A - a) \times (L + l) = AL + Al - aL - al\,;$$

and, neglecting the product al, which is small with respect to the others, the total volume becomes $= Al - aL$, and the increment due to i,

$$\frac{Al - aL}{AL} \tag{11}$$

But if the bar be exposed to compression in all three axes, L, B, D, simultaneously by forces perpendicular to its faces (assumed a square prism), and the pressure on L, be that as before on A; L, B, and D being respectively the length, breadth, and thickness of the bar, then the compression of the bar in L shall be only half the former, and the volume of the whole bar becomes

$$LBD\,(1 - \tfrac{1}{2}i)^3 = LBD - \tfrac{3}{2}i\,LBD$$

the decrement due to i being

$$\tfrac{3}{2}i\,LBD. \tag{12}$$

Neglecting the functions of the small fraction of i as before, the cubic contraction or expansion of the bar in this case is measured by $\frac{3}{2}i$.

116. Now, when a bar of a homogeneous metal is heated, and expands in all directions alike, forces analogous to those above, but acting in opposite directions from within the mass, may be considered as applied perpendicular to the faces of the prism; but the increase or decrease of volume is altogether different, being twice the former, $\frac{6}{2}i = 3i$ (i being in this case the lineal expansion or

contraction due to a given difference of temperature), in accordance with the well-known fact, that the dilatation in bulk of solids is (*quam prox.*) three times the lineal expansion.

This singular result, which, it should be mentioned, however, is not fully confirmed by the experimental facts of Wertheim (Ann. Ch. Ph. t. xxiii. p. 52), would seem to indicate a radical difference, in the nature of the molecular forces, which resist change of form by mechanical force, and those which are developed in the change of volume by heat, and therefore that we should at present take with some reserve the conclusion commonly asserted by physical writers on heat, that " The mechanical force brought into operation by change of temperature in the expansion or contraction of a bar of metal through a given fraction of its length, $\frac{l}{L}$, is precisely equal to the mechanical force required to extend or to compress the bar by the same fraction." We shall return to this subject hereafter, in considering the construction of wrought-iron guns built up in rings.

For all cases of a practical character in construction, the change of volume in relation to the lineal elasticity is small, and may be neglected; we are, therefore, concerned at present only with lineal elasticity, as a resistance to force applied in one or in two rectangular axes, and may also pass by the elasticity of torsion, which Mr. Rankine, in common with some other physicists, in an able paper (Institut. for 1850), makes a third and separate class.

117. Continuing our last notation: the prismatic bar, whose length is L and cross section A, is extended or compressed in length by a force P, and suffers an extension or compression l, which is proportional to its length, so that $\frac{l}{L}$ is a constant $= i$ for unit of length.

The elastic resistance which balances this force ϵ, on the unit of surface, is measured by $\epsilon \times A$, or by

$$\frac{P}{i} = P\,\frac{L}{l} \text{ or } P = \epsilon A i = \epsilon i,\ A \text{ being} = 1. \tag{13}$$

Assuming that elasticity remained perfect, and such that the bar would bear to be extended or compressed by a range equal to its own length, we have in the equation

$$P = \epsilon A i$$
$$A = 1, l = L, \text{ and } i = 1; \text{ so that when} \qquad (14)$$
$$P = \epsilon,$$

then ϵ is the modulus of elasticity, or the force that for a given material on the unit of section (= 1 square inch) should be equal to compress or extend the bar its own length; a purely arbitrary constant, which may be conveniently expressed in terms of the length of the bar; for if δ = its specific gravity, and R = the breaking weight, or force, for unit of cross section, L the length $= \frac{R}{\delta}$ or modulus of cohesion, and $L_e = \frac{\epsilon}{\delta}$ or $\frac{P}{\delta}$ the modulus of elasticity, and as here $i = 1$, if i' be such a fraction of the extension or compression as belongs to the point at which the elasticity is crippled, $\frac{\epsilon}{\delta} i'$ may be used to express the modulus of *elastic limit*.

118. The property of elastic, or rather of imperfectly elastic bodies, as we find them in nature, is that at a certain limit of force, their elastic resistance gives way altogether, and the body, whether by extension or compression, becomes *crippled*, when after a certain range, greater or less, a new equilibrium is established, and so on until at length, by a further application of force, it becomes ruptured or crushed. When the actual strain bears a large proportion to that of rupture, the element of the duration of its application can never be in strictness neglected. Vicat showed, by experiments made before 1833 ("Ann. de Chem. et Phys.," t. liv. p. 38), that when the actual strain did not exceed one-fourth that of rupture, the extension of wrought-iron which took place almost immediately, did not increase by time, but that with strains above this proportion, the extensions slowly increased, in a ratio which was directly as the time, and for equal times, was directly as the tension or strain. Thus, also, a strain almost, or perhaps altogether, capable, after some time, of producing rupture, may be borne with impunity for a very brief interval; so that a gun may sustain, without injury, during the momentary expulsion of the shot, a pressure that, continued for some longer time, would burst it.

Vicat's brief but conclusive experiments, made about five years anterior to the publication of Mr. Fairbairn's, on cast-iron, seem to have been quite unknown to that gentleman, as well as the elaborate experiments of the

Franklin Institute, on tension at high temperatures, equally unnoticed by him.

119. Poncelet has devised a coefficient to express the relation of the work done by the force balancing this resistance, at each of these limits: the one T_e, which he calls that of "resistance vive d'elasticité;" the other, T_r, that of "resistance vive de rupture." They express respectively the work done by the force P moving through the space i, up to the limit where elasticity is lost or materially altered, and up to that of rupture or crushing; in both cases as the nearly immediate results of application of the force.

For the resistance vive of elasticity, as $P = \epsilon i$, we have

$$T_e = \tfrac{1}{2} Pi \text{ or } \tfrac{1}{2}\, \epsilon i^2 \,; \tag{15}$$

and a similar expression applies to T_r, increasing the values of P and i in either case for each special substance.

120. The force P is variable between the limits o and i—

$$i = \frac{PL}{\epsilon A} \text{ and } P = \frac{\epsilon A}{L} i \tag{16}$$

If x be any small extension or compression the n^{th} part of i, the P, corresponding to $x = \frac{\epsilon A}{L} x$, the work done in extending or compressing through the infinitely small additional space Δx (assumed uniform) $= \frac{\epsilon A}{L} x \Delta x$, and the whole work done,

$$T_e = \frac{\epsilon A}{L} \int_o^i x dx = \frac{1}{2} \frac{\epsilon A}{L} i^2 \text{ or } \tfrac{1}{2} \epsilon i^2 \text{ for unit of } L \text{ and } A \text{ as above.} \tag{17}$$

121. If the strain P, due to i, the extension or compression, be brought at once upon the bar, then the work done upon the bar will be double the former $= \frac{\epsilon A}{L} i^2$ and the extreme extension or compression will be $2i$, and the end of the bar i, will oscillate from o to $2i$, making equal excursions at either side of i.

If between equations $i = \frac{PL}{\epsilon A}$ and $T_e = \frac{1}{2} \frac{\epsilon A}{L} i^2$ i be eliminated, we have

$$T_e = \tfrac{1}{2}\frac{P^2 L}{\epsilon A}, \tag{18}$$

indicating that the work done by any strain in extension or compression of an elastic bar varies directly as the square of the strain, times its length, and inversely as its cross section, times the modulus of elasticity of its material. (Moseley.)

122. Poncelet has investigated, with his usual adroitness, a number of questions relating to the oscillatory movement of bars subjected to constant strain and to impulses, separately or together, which are of the highest interest in relation to the peculiar class of strains brought upon artillery at the moment of discharge. There are three principal cases:—

1°. Where strain possesses no initial velocity, as in that just considered.

2°. Where the strain does possess an initial velocity—impulse.

3°. Where a permanent strain being on the bar, it is subjected to that of an impulse in addition.

123. Case I.—As has been already stated, the maximum extension or compression, $2i$, is double that due to the statical extension or compression, i; while the extension or compression at the point of maximum velocity of oscillation, is one-half the maximum, or equal to the static $= i$.

Let $2i = l'$ the maximum, and l be the extension or compression due to some intermediate point in the range of oscillation of the strain P and of the adjacent extremity of the bar; then the velocity due to any extension or compression, l, is

$$\frac{P}{g}\, V^2 = 2\left(Pl - \tfrac{1}{2}\frac{\epsilon A}{L}\, l^2\right) = \left(2P - \frac{\epsilon A}{l}\, l\right) l; \tag{19}$$

or, more simply, since $P = \epsilon A i = \epsilon A \frac{l'}{L}$, suppressing the common factors,

$$V^2 = \frac{g}{l'}\left(2l' - l\right) l, \tag{20}$$

and extracting the square root, and making $\sqrt{\left(\frac{g}{l}\right)} = \sqrt{\left(\frac{g\epsilon A}{Pl}\right)} = k$, g being the coefficient of gravity, $= 32\frac{1}{12}$ feet,

$$V = k\sqrt{\{(2l' - l)\, l\}} \tag{21}$$

The coefficient k is readily obtained, g and l' being both known. $\sqrt{\{(2l'-l)\,l\}}$ is a mean proportional between $2l'-l$ and l, and is also had when l is given.

It may be also shown that

$$V = kl,\ sin,\ kT, \tag{22}$$

T being the time from the commencement of motion, when the extension or compression is l, and the time due to l', the maximum expansion or compression is

$$T = \frac{\pi l'}{kl'} = \frac{\pi}{k} = \pi\sqrt{\left(\frac{l'}{g}\right)} = \pi\sqrt{\left(\frac{PL}{g\epsilon A}\right)}, \tag{23}$$

π being $= 3{\cdot}1416$, the ratio of the circumference to the diameter; so that the time of one complete oscillation is double this, or,

$$T' = \frac{2\pi l'}{kl'} = \frac{2\pi}{k} = 2\pi\sqrt{\left(\frac{l'}{g}\right)} = 2\pi\sqrt{\left(\frac{PL}{g\epsilon A}\right)}; \tag{24}$$

and the number of complete oscillations per second of time

$$N = \frac{1''}{2\pi}\sqrt{\left(\frac{g}{l'}\right)} = \frac{1''}{2\pi}\sqrt{\left(\frac{g\epsilon A}{PL}\right)}, \tag{25}$$

in which it may be remarked that inversely $N : T_e$. The mean velocity of oscillation being equal to twice the amplitude $2l'$ divided by the time, or to $4l'N$, is given by the expression

$$\frac{2l'k}{\pi} = \frac{2}{\pi}\sqrt{(gl')} = 2\sqrt{\left(\frac{gPL}{\epsilon A}\right)}. \tag{26}$$

The effect of the strain P producing acceleration at any moment, T, which effect is the whole of P at the moments that the oscillation begins and ends, is

$$P(1 - \text{cosin}\ kT), \tag{27}$$

that is to say, its periodicity varies with l, assuming as is done throughout, that the extensions or compressions are proportionate to the extending or compressing forces, and that between o and l' the elasticity of the bar remains perfect.

124. CASE II.—When the straining load possesses an initial velocity. Here the work done by the initial velocity, half the *vis viva* of $\frac{P}{g}$ at the moment it reaches the bar, together with the work done by P, times the height l'', must be

equal to the work done in the opposite direction by the elastic resistance of the bar, or

$$P\frac{V_{\prime}^2}{2g}+Pl''=\tfrac{1}{2}A\epsilon Ll''^2, \tag{28}$$

V being the initial velocity.

While the elasticity is perfect, the law of the oscillation is the same as in the former case, but the extent of their excursions is greater.

The static extension or compression, l', is also that at the moment of maximum velocity,

$$l'=iL,$$

and the maximum extension or compression

$$l''=l'+\sqrt{\left(l'^2+\frac{V_{\prime}^2}{k^2}\right)} \tag{29}$$

or, replacing l' and k by their values,

$$l''=\frac{PL}{\epsilon A}+\sqrt{\left(\frac{P^2L^2}{\epsilon^2A^2}+\frac{PL}{g\epsilon A}V_{\prime}^2\right)} \tag{30}$$

or for the unit of length,

$$l''=\frac{P}{\epsilon A}+\sqrt{\left(\frac{P^2}{\epsilon^2A^2}+\frac{P}{\epsilon A}\,\frac{V_{\prime}^2}{gL}\right)} \tag{31}$$

If P' be the effort capable of producing statically or permanently the maximum extension or compression (within the limit of perfect elasticity), we have

$$P'=P+\sqrt{\left(P^2+P\epsilon A\frac{V_{\prime}^2}{gL}\right)}=P+P\sqrt{\left(1+\frac{V_{\prime}^2}{gl'}\right)}; \tag{32}$$

so that the excess of this over that of P, as well as the excess of the extension or compression $\sqrt{\left(l'^2+\frac{V_{\prime}^2}{k^2}\right)}$, both increase with the initial velocity $V_{\prime}$ but more gradually in proportion as the actual length L of the bar is greater.

In the second half of each complete oscillation, or that in the opposite direction to the commencing movement (whether due to extension or compression), there will in this case be a contraction of the bar, or an extension beyond its primary limits due to the reaction of the moving strain, acting in the reverse direction at the termination of the oscillation; this is given by the expression,

$$\sqrt{\left(l'^2+\frac{V_{\prime}^2}{k^2}-l'\right)}. \tag{33}$$

The equation for maximum extension may be put in a more convenient form, for k^2 being $=\frac{g}{l'}$ if we call H the height $\frac{V_{\prime}^2}{2g}$ due to $V_{\prime}$, it becomes,

$$l''=l'+\sqrt{\left(l'^2+2gH\frac{l'}{g}\right)}=l'+\sqrt{[l'(l'+2H)]}, \tag{34}$$

which shows that l'' exceeds l', the static extension or compression due to P by a mean proportional between l' and $l'+2H$. This, therefore, measures the effect due to the initial velocity of the straining load.

If $r=$ the semi-amplitude of oscillation, or $2r$ the amplitude,

$$r=\sqrt{\left(l'^2+\frac{V_{\prime}}{k^2}\right)}. \tag{35}$$

If then T' be the time corresponding to $\sqrt{\left(l'^2+\frac{V_{\prime}^2}{k^2}\right)}-l'$, and T the time when the end of the bar has reached any extension or compression l,

$$l=l'-r\text{ cosin }k\,(T+T'), \tag{36}$$

and the velocity at the corresponding point

$$V=k\sqrt{[r^2-(l'-l)^2]}=kr\;sin\;k\,(T-T'), \tag{37}$$

the value of the corresponding effort of the straining force being

$$P'=\frac{Pl}{l'}. \tag{38}$$

Lastly, the time of one complete oscillation,

$$T=\frac{2\pi}{k}=2\pi\sqrt{\left(\frac{l'}{g}\right)}=2\pi\sqrt{\left(\frac{PL}{g\epsilon A}\right)}, \tag{39}$$

and the number of oscillations per second,

$$N=\frac{1''}{T}=\frac{1}{2\pi}\sqrt{\left(\frac{g\epsilon A}{PL}\right)}. \tag{40}$$

From what has been stated it is obvious that if, in place of the straining load having an initial velocity, we have an elastic bar strained with a static load, and

that we extend or compress it by a further static strain, and then suddenly relieve it of this latter, the train of phenomena produced will be precisely the same as in this last case, and the same formulæ will represent them.

And it is further obvious, that if the inertia of the bar itself be so considerable as to be taken into account, similar phenomena will, upon its being slowly extended or compressed and then at once let go, present themselves. To express these, and many other varieties of condition of this problem, that will at once suggest themselves, some modifications of the formula would be needed. These questions, however, are of less practical value.

125. CASE III.—Where there is a permanent strain upon the bar, and it is also subjected to an impulse from a new strain having an initial velocity, it follows from the laws of impact, that if the strain and the impulse be both due to solid bodies, the first, forming part of the bar (or even being the bar itself), and the second a solid striking it with a determinate velocity, then the common velocity after contact will depend upon the elasticity and range of the striking bodies. After several oscillations, and the system has come to rest, we have for equilibrium,

$$l' = \frac{PL}{\epsilon A} + \frac{1}{2}\frac{pL^2}{\epsilon A}, \tag{41}$$

p being the weight of the unit in length of the bar.

Let P be the permanent strain, and P' the impulsive, with the velocity V' due to H', so that $V' = \sqrt{(2gH')}$. Then, on the principles already established the maximum extension would be that due to the descent of $P + P'$ through H', and the equation of work done by the strain, and by the bar, would be,

$$\frac{1}{2}\frac{P}{g}V'^2 = \epsilon A i, \tag{42}$$

if no change of form occur in P and P', and the inertia of the bar be neglected.

The loss of *vis viva* will depend upon the degrees of compression of P and P' and upon the extensibility of the bar L; the compression being greatest if the extensibility was $= 0$, and least, if P was free to move under the effect of P' without restraint from the bar, or its resistance $= 0$.

If v and v' be the velocities lost and gained in the infinitely short time t, and $F =$ the variable force of reaction, M and M' being the masses of P, P',

$F=M\frac{v}{t}=M'\frac{v'}{t}$ and $M\frac{v'}{t}$, and Mv being always $=M'v'$, during the range of compression,

$$F-P'=M'\frac{v'}{t}, \quad F+P-\epsilon Ai=M\frac{v}{t}. \tag{43}$$

Where the bodies are very compressible, so as considerably to diminish the intensity of F in the directions $+$ or $-$ according as P acts with or against P' substituting the value of $F=P'+M'\frac{v'}{t}$ as above, we have,

$$P'+M'\frac{v'}{t}+P-\epsilon Ai=M\frac{v}{t}, \text{ or } (P+P'-\epsilon Ai)\,t=Mv-M'v'. \tag{44}$$

If on the contrary the masses M, M' are such that their mutual compressions during the time of impulse, may be considered insensible with relation to l, which will always be the case when the masses are large, and their range of elasticity small (hardness great), and the length and extensibility of the bar relatively great,—then, as

$$F=Mv=M'v',$$

M and M' assume the common velocity V'', and

$$V''=\frac{P'}{P+P'}V', \tag{45}$$

at the first instant of extension or compression of their bar, and their work upon the bar is $(M+M')\,V''=M'V'$, or the initial *vis viva*,

$$(M+M')\,V''^2=\frac{M'}{M+M'}M'V'^2=\frac{P'}{P+P'}M'V'^2=\frac{2P'^2H'}{P+P'}; \tag{46}$$

and the corresponding loss of effect (as M and M') are supposed to remain in contact,

$$\frac{M}{M+M'}M'V'^2=\frac{P}{P+P'}M'V'^2. \tag{47}$$

Lastly, if the mass M, instead of being at rest, had a previous velocity V''', either in the same or in the opposite direction to V' (and to which a given

extension, or compression l, of the bar was due): then the common velocity, as before,

$$V'' = \frac{M'V' \pm MV'''}{M+M'} = \frac{P'V' \pm PV'''}{P+P'}, \tag{48}$$

and the initial *vis viva*,

$$(M+M')V''^2 = \frac{(MV' \pm MV''')^2}{M+M'} = \frac{(P'V' \pm PV''')^2}{g(P+P')}. \tag{49}$$

126. We have now to determine the conditions of the first oscillation, for if the elasticity of the bar then remain uninjured, it is subjected to no greater strain by any subsequent one. Half the *vis viva*, plus the work done by $(M+M')$, acting through the height due to the extension of the bar from the moment of impulse, l', must be equal to

$$\tfrac{1}{2}Pl' = \tfrac{1}{2}P\frac{PL}{\epsilon A} = \tfrac{1}{2}\epsilon ALi'^2; \tag{50}$$

and this, if the elasticity of the bar remain uninjured, must not exceed the value of

$$T_e = T_e'AL, \quad T_e \text{ being} = \tfrac{1}{2}\epsilon ALl^2, \tag{51}$$

or if it be just not broken, must not exceed that of

$$T_r = T_r'AL. \tag{52}$$

The maximum extension, assuming the former, and that P has no initial velocity, L' being the length of the bar when most elongated or compressed, and I the proportional extension or compression corresponding, is

$$(P+P')\frac{V''^2}{2g} + (P+P')(I-i')L + \tfrac{1}{2}\epsilon ALi'^2 = \tfrac{1}{2}\epsilon AI^2, \tag{53}$$

which may take a simpler form, for, multiplying all the terms by $\frac{2L}{\epsilon A}$, we have

$$L' = LI, \quad P = \epsilon Ai' = \epsilon A\frac{l'}{L}, \quad \text{or } \frac{P}{\epsilon A} = i' = \frac{l'}{L}, \quad \frac{PL}{\epsilon A} = l';$$

and if i'' be the proportional extension or compression, and l'' the actual, produced in the bar, by a static strain equal to P', the impulsive body, by analogy,

$$\frac{P}{\epsilon A} = i'' = \frac{l''}{L}, \quad \frac{P'L}{\epsilon A} = l'',$$

the equation then becomes

$$\frac{(l'+l'')}{g} V''^2 + 2(l'+l'')(L'-l') + l'^2 = L'^2 \,; \tag{54}$$

and abridging, as before, by making

$$k' = \sqrt{\left(\frac{g}{l'+l''}\right)} = \sqrt{\left(\frac{g\epsilon A}{(P+P)L}\right)};$$

we have

$$L' = LI = l' + l'' \pm \sqrt{\left(l''^2 + \frac{V''^2}{k'^2}\right)}; \tag{55}$$

twice which $\sqrt{\left(l''^2 + \frac{V''^2}{K'^2}\right)} \pm (l'+l'')$, corresponds to the maximum elongation or compression, and the smaller value to its minimum, if the sign be +, or to its maximum if it be −, that is to say, according as P' acts with or against P, assuming always that M, M', and L remain in contact after the impulse of M'.

127. The fundamental equation of motion, by which the velocity V, common to M and M' at any point, where $l = Li$, is obtained on the principle of *vis viva*. For the increment of *vis viva* of M and M', since the commencement of motion $(M+M')(V^2 - V''^2)$ is double the work $(P+P')(l-l')$ developed in them and due to the $H' = l - l'$, less by twice the work,

$$\tfrac{1}{2}\epsilon A L\,(i^2 - i'^2) = \tfrac{1}{2}\frac{\epsilon A}{L}(l^2 - l'^2),$$

which is thus developed in the opposite direction by the elastic resistance of the bar $\epsilon A i$, during the time due to $H' = l - l'$.

To obtain V, therefore, by means of l, we have,

$$\frac{(P+P')}{g} V^2 - \frac{(P+P')}{g} V''^2 = 2(P+P')(l-l') - \frac{\epsilon A}{L}(l^2 - l'^2),$$

multiplying all the terms by $\frac{L}{\epsilon A}$,

$$\frac{V^2}{k^2} - \frac{V''^2}{k'^2} = 2(l'-l'')(l-l') - l^2 + l'^2 = l''^2 - (l'+l''-l)^2.$$

The time of one complete oscillation is

$$T=\frac{2\pi r'}{k'r'}=2\pi\sqrt{\left(\frac{l'+l''}{g}\right)}=2\pi\sqrt{\left(\frac{(P+P)L}{g\epsilon A}\right)},$$

$$k' \text{ being } =\sqrt{\left(\frac{g}{l'+l''}\right)}=\sqrt{\left(\frac{g\epsilon A}{(P+P')L}\right)},$$

and

$$r'=\sqrt{\left(l''^2+\frac{V''^2}{k'^2}\right)},$$

k' and r' corresponding to k and r in the equation of preceding cases. The number of oscillations per second is therefore,

$$N=\frac{I''}{T}=\frac{k'}{2\pi}=\frac{I}{2\pi}\sqrt{\left(\frac{g}{l'-l'}\right)}=\frac{I}{2\pi}\sqrt{\left(\frac{g\epsilon A}{(P+P')L}\right)}.$$

It may be shown that the entire elongation or compression of the bar l at any instant of its motion t is given by the equation

$$l=l'+l''(1-\cos k'T)+\frac{V''}{k'}\sin k'T,$$

$$l' \text{ being } =\frac{PL}{\epsilon A},\quad l''=\frac{P'L}{\epsilon A},\quad V''=\frac{P'}{P+P'}.$$

128. It follows from the foregoing, that the period and time of oscillations produced in elastic bars, by longitudinal extension or compression are independent of the intensity or the velocity of the impulse producing them, and depend upon the product of the cross section of the bar, multiplied into the coefficient of elasticity of its material, upon the absolute length of the bar, that oscillates, and upon the original strain of compression or tension, under which it oscillates,—in all cases assuming the elasticity to remain perfect, and that the strain remains constant for the whole of the oscillation.

129. Professor Hodgkinson and others have shown that strains, however feeble, produce some permanent elongation or compression in iron, and the same is probably true for all materials. Perfect elasticity, therefore, is not found in the nature of solids, and investigations founded upon its assumption can only be taken as general guides in practice. Professor Hodgkinson's results (Trans. Brit. Assoc.) infer, that in the case of cannon, every discharge must permanently injure

the gun, though for a great number of rounds, perhaps, quite imperceptibly; but the injury effected by each successive discharge goes on in an increasing ratio, and after a certain number, more or less, must end in the destruction of the gun;—yet that when the value of the constant T_e is high, and the surplus of strength to the impulse large, as in the case of the forged wrought-iron barrels of small arms, this process of gradual destruction by use is inconceivably prolonged, as evidenced by the endurance of old firelocks and fowling pieces, from many of which, thousands of shots have been fired without perceptible deterioration.

130. In all the foregoing equations, the metallic bar has been supposed a straight uniform prism, fixed at one end, and loaded or otherwise strained (in extension or compression) at the other. But if for L we substitute its value, $2\pi R$, in assuming the bar bent round and united at its extremities into a ring, to form a portion of the cylinder of a gun, all the equations will equally apply to the tangential strains, while they apply directly to the longitudinal ones. If the value of A be assumed small, i. e. a unit of section of the whole thickness of the gun, then $2R$ may be taken = the caliber, for the portion of metal exposed to the greatest strain; but if the whole thickness of the gun be included in A, and for a determinate length along its axis, then the value of R must be taken at an intermediate point between D' and D'' (Eq. 1), to be specially ascertained, where the mean of the tangential strain, variable in the radius, shall be situated.

131. In fact it is plain that a unit in length and thickness of the gun may be viewed as an elastic hoop, expanding and contracting under impulse, the maximum elongation being measured from an imaginary point of origin taken anywhere in its circumference; and, as we found (Eq. 20, 22) that the extension or compression due to P, when suddenly applied, is $= 2i$, so, in calculating the stress upon the unit of section of the metal of the gun, we must take the extension or compression as double that due to the maximum pressure of the elastic gases per square inch, and only give such a value to R (in Eq. 1) as will satisfy this condition, without crippling the particular metal to which we may apply our calculations. It would appear to be from ignorance of this, and the reliance upon conclusions as to extension or compression of the materials, based upon the assumption of merely *statical* strains, that many failures of newly projected guns, have latterly occurred.

132. In the physical conditions of application of the impulse as produced by the explosion of powder, however, there are some important differences from any of the cases of application of the strain already assumed, besides that of the total withdrawal of the strain or impulse, almost immediately after its application, and depending on conditions the precise nature and constants of which are as yet so imperfectly known that it would be useless to pursue the application of analysis to them at present.

133. Amongst the most important data required is an experimental knowledge of the rate at which gunpowder inflames in relation to the whole mass, and the curve which shall represent the increase, and subsequent decrease, of pressure on the interior of the gun, from the first instant of ignition, to the moment that the ball leaves the muzzle. (Note L.) Certain formulæ are given in gunnery class-books, purporting to represent the time of inflammation of powder, based on the assumption that its grains are spherical and equal, and that the time of burning inwards from the surface to the centre of each sphere, is the same as for the whole mass. The assumption is, however, perfectly fallacious, for obvious reasons.

But a true result may be arrived at experimentally by a suitable arrangement of galvano-chronometric apparatus with much facility and accuracy; indeed, the author has already (incidentally to his experiments on the rate of transit of earthquake waves in solids, by means of the explosion of small mines) had occasion to determine the time of inflammation for a mass of 25 lbs. of powder (Trans. Brit. Ass., 1851); it would be most desirable that such an inquiry were pursued. Equally so would it be that the curve of pressure within the gun, during the ball's traject through it should be ascertained experimentally. There seems little ground for doubt, that apparatus could be applied to a gun on the principle of the manometer, or rather of the aneroid, or of Bourdon's pressure gauge, such as to receive the pressure as in the interior of the gun, with which it should communicate, and to register it at once in the form of a curve, for every instant of that fraction of a second, occupied by the ball's traject through.

134. From the extreme rapidity with which the pressure increases within the gun from the moment of ignition up to the point of maximum, a condition of the matter of which it is formed, related to its elasticity, and dependent upon

which is *the rate at which force itself* is transmitted through its mass, becomes not wholly unimportant. The formula

$$V = \sqrt{\left(\frac{2g(h)d}{\epsilon D}\right)},$$

in which d and h are the density of mercury at zero, and the height of the barometric column at 30 inches, expresses the velocity of sound in any solid whose modulus of elasticity is E and density D (omitting the coefficient for heat due to compression), and also expresses the velocity with which any impulsive force whatever is transmitted through the same solid. This transit rate, then, is proportionate to $\sqrt{\epsilon D}$, and for

Gun-metal, ...	: – 151
Cast-iron, ...	: – 203
Wrought-iron, ...	: – 239
Steel, ...	: – 258

proportionate, omitting decimals, to the numbers severally annexed. The actual velocity is great in every case, being, probably, not less than 11·090 feet per second for cast-iron, as determined by Biot and Malus; but it is observable that its rate in gun-metal is not much more than $\frac{3}{5}$ that in steel. Were it possible to have a gun of sufficient thickness, therefore, the impulsive effect of the explosion might have reached its maximum and vanished altogether before the strain visited on the interior portions had been transmitted to the exterior. This cannot occur in practice, but in no case is the *whole* of the impulse transmitted equally through the whole thickness of the gun, and the less as the above numbers are smaller. There cannot be a doubt that this, coupled with the ductility of gun-metal, is one of the causes why guns of that material bear without destruction such heavy charges.

135. Again, as cast-iron is a crystallized body, and its planes of crystallization variously arranged, as already shown (Chapters 3 and 4), and the elasticity of the integrant crystals probably different in different axes, it follows that the same internal impulse will not be transmitted at the same rate through the mass of the gun, in the directions of these rectangular axes. Hence probably another reason why impulsive or shattering forces act so injuriously upon it.

136. In concluding this discussion of the relations of elasticity only, to the materials for constructing artillery, it will be desirable to make clear the still more important relations of ductility and ultimate strength upon which the values of the coefficients of resistant *vis viva* of elasticity T_e and of rupture T (already referred to) depend.

137. The following Tables, IV. and V., give the results of the experiments upon direct extension made by M. Ardant of the French Corp de Genie, and by M. Bornet, for steel in its several conditions, harsh and ductile wrought-iron, and hard and annealed brass; and Table VI. the relation of elastic limit and extension, to ultimate cohesion:—

Table IV.

Experiments of M. Ardant *on the Elongations per Metre in length of Wires, under Tensile Strains increasing up to Rupture.*

Strain in Kilogrammes per Millimetre square.	Steel Wire.			Iron Wire.		Brass Wire.		Strain in Kilogrammes per Millimetre square.	Steel Wire.
	As Drawn.	Annealed, not hardened.	Blue Temper.	Hard and not annealed	Soft and annealed.	Hard and not annealed.	Soft and annealed.		Hardened at a bright-red heat, and not tempered.
K.	Mil.	Mil.	Mil.	Mil.	Mil.			K.	
5·0	0·25	0·24	0·23	0·26	0·294	0·55	0·45	2·49	0·59
10·0	0·56	0·48	0·48	0·52	0·588	1·11	0·90	4·97	0·83
15·0	0·81	0·72	0·72	0·78	0·882	1·70	1·35	7·46	1·08
20·0	1·02	0·96	0·96	1·04	1·176	2·28	1·80	9·95	1·39
25·0	1·25	1·20	1·20	1·30	1·470	2·98	2·25	12·44	1·58
30·0	1·50	1·44	1·44	1·56	2·500	3·70	7·30	14·92	1·87
32·5	,,	,,	,,	,,	13·000	,,	,,	15·57	rupture.
35·0	1·80	1·68	1·68	2·22	14·100	4·43	10·80		
40·0	2·10	1·92	1·92	2·40	18·000	5·20	49·90		
42·5	,,	,,	,,	,,	20·500	,,	,,		
45·0	2·36	2·16	2·16	2·82	rupture.	6·15	115·00		
49·0	,,	,,	,,	3·10		7·19	rupture.		
50·0	2·65	2.40	2·40	rupture.		rupture.			
52·5	,,	,,	2·52						
55·0	3·00	2·66	rupture.						
57·0	3·15	2·76							
,,	rupture.	rupture.							

The diameters of the wires were from 0·40 to 1·60 millimetres, and the lengths from 1 to 1·5 metres.

TABLE V.

EXPERIMENTS OF M. BORNET *on the Elongation per Metre of soft ductile round Wrought-Iron Bars, used for making Chain Cable, under increasing Tensile Strains up to Rupture. Diameter of Bars,* 49·5 *millimetres; Length* 6·42 *metres.*

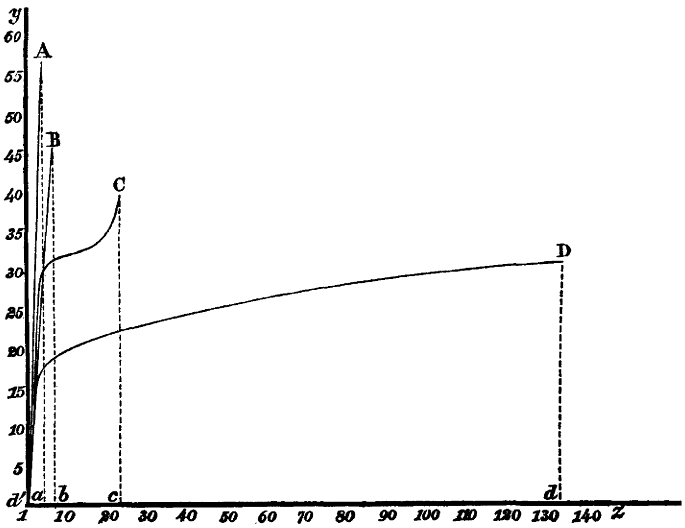
Strain per Millimetre square in Kilogrammes.	Elongations per Metre.	First Difference.	Second Difference.
2	0·08		
		·08	
4	0·16		·07
		·15	
6	0·31		·10
		·05	
8	0·36		·06
		·11	
10	0·47		·03
		·08	
12	0·55		·06
		·14	
14	0·69		·03
		·17	
16	0·86		1·17
		1·34	
18	2·20		12·22
		13·56	
20	15·76		4·98
		8·58	
22	24·34		1·87
		10·45	
24	34·79		1·72
		12·17	
26	46·96		8·57
		20·74	
28	67·70		0·95
		21·69	
30	89·39		21·40
		43·09	
32	132·48		
33	rupture.		

TABLE VI.

RELATION *of Elastic Limit, and of Extension, to ultimate Cohesion, according to Continental Experimenters, in English Measures.*

NATURE OF THE METAL, AND AUTHORITY.	Elongation at limit of Elasticity. / Length of Bar = 1.0.	Corresponding strain in pounds per square inch.	Ratio to the ultimate Cohesion.	Value of Coefficient of Elasticity in lbs. per square inch.
Wrought-iron bars, highest, .	·00167	30·000	0·63	34·133·400
Ditto, (Duleau), mean, . .	·00062	17·634	0·36	28·444·500
Ditto, (Lagerhjilm), mean, .	·00072	21·349	0·40	29·440·100
Strong bars (Navier), ...	·00093	25·600	0·45	25·591·165
Iron wire (1·2 mil. diam.), hard,	·00084	21·300	0·33	26·026·718
Ditto, (Ardant), soft, . . .	·00088	21·300	0·50	24·177·825
Cast-steel, English blue temper,				
Ditto, (Morin) mean, . . .	·00222	93·866	0·67	42·666·750

138. From these Tables the succeeding diagram has been produced, in which the quadratures of the four curves indicate the values of T_e and T_r for cast-steel, harsh strong iron, soft strong iron, and wrought-iron of extreme ductility, but of moderate strength.



From d, the origin, dy is the ordinate of strain, in kilogrammes, and dz the abscissa of extension, in millimetres. The curve $d'A$, nearly a right line, is that for the extension of cast-steel; the curve $d'B$ that for harsh strong wrought-iron; $d'C$ the curve for soft strong iron; and $d'D$ that for extremely ductile, but not very strong iron.

139. On the known principles of *vis viva*, the "work done" in each case in producing these extensions will be equal to one-half the quadrature of each

respective curve. It is obvious, then, to the eye, that although the strength of cast-steel (its ultimate cohesion) is enormously greater than that of the very ductile iron, still, from the greater range of extension, of the latter, in the abscissa $d'z$, the "work done" in producing its extension to final rupture, or even its extension within the elastic limit, is enormously in excess of that required to bring the cast-steel up to its point of rupture. In fact, in round numbers, *it will require of any force in motion, above fifty times the effort to rupture a given section and length of ductile wrought-iron, that will rupture the best and toughest cast-steel; while again, for the very ductile wrought-iron, its value for* T_r *is nearly six hundred and fifty times that for* T_e, *so great is the range or limit of work to be done, between the elastic (safe) limit and that of rupture.*

140. Hence it follows, that a gun formed of cast-steel, or of harsh strong wrought-iron, provided it have an enormous surplus of strength above the highest strain to which it is to be exposed, will be very safe; but if its proportions be reduced within a narrower limit of balancing the final resistances with the bursting strain, or if the latter be brought up, accidentally or otherwise, so as to approach such balance, *the cast-steel or the harsh wrought-iron will be the most unsafe gun possible, while in all cases the gun of ductile iron will be the safest.* This might be popularly illustrated by saying that the former gun approximates to one of enormous strength, but *made of glass*, while the latter approximates to a gun made of sufficient strength, if conceivable, of leather or of India-rubber, or to the silk-wrapped guns of the Chinese.

141. The highest possible ultimate cohesion is, no doubt, most desirable; but this quality *alone* will not answer for ordnance (or for any other purpose in which impulsive strains are concerned): it must be united with the largest possible amount of ductility within the elastic range, to give security, or otherwise security must be purchased by the accumulation of an immense overplus of material. Were it possible to procure some variety of wrought-iron or of steel that should possess the great ultimate cohesion of the latter, united with the long range of extension of soft ductile, such wrought-iron as is used for making chains or rivets of, we should obtain the *ne plus ultra* of a material for the fabrication of artillery; but the latter indispensable quality appears, in the present state of metallurgic science, incompatible with the nature of steel in any form. The attempts, therefore, recently made, at great expense, to fabri-

cate guns of German steel, seem a step in a wrong direction, and made in ignorance or in defiance of the first principles that should guide us. (Note M.)

142. The following Table will make this conclusively clear for the material in question:—

TABLE VII.

RESISTING POWERS *of the Cast-Steel of Herr Krupp, Essen, Westphalia, as compared with other Metals for constructing Ordnance. From Report by the Prussian Ministry of War, Berlin.*

No.	Metal.	Ultimate Resistance to Tension per square inch.	Ultimate Resistance to Torsion.	Angle of Torsion before Rupture.	Value of T_r deduced.
		lbs.	lbs.	Degs.	
1	Krupp's Cast-Steel, No. 1 (Ein kron), .	117·213	36·300	207°	3·757·050
2	" " 2 " .	110·393	40·140	182°	3·652·740
3	" " 3 " .	107·516	34·620	221°	3·825·510
4	Wrought-Iron, " 1	73·138	25·020	322°	4·028·220
5	" " 2	64·323	—	—	—
6	Cast-Iron, ...	19·341	17·510	12°	105·060
7	Gun-Metal, 10 per cent. Tin, ...	43·536	20·430	400°	4·086·000
8	" 9 " "	41·454	20·810	386°	4·016·330
9	" 11 " "	36·615	20·320	315°	3·200·400
10	" 12 " "	32·334	18·300	130°	1·189·500

NOTE.—The direct tension experiments were made by Lieutenant-Colonel Orges, at Brunswick, on ¾-inch square bars, by means of an hydraulic-press proving machine; the experiments on torsion, by Lieut.-Colonel Weber. The Report erroneously deduces from his results, that Krupp's steel has an approximate *stability* (Festigkeit—quere Zähigkeit?), the double of that of the best bronze.

143. On examining the third column of this Table it will be observed that the ultimate cohesion of German cast-steel is nearly twice as great as that of wrought-iron, six times as great as that of cast-iron, and from two and a half to three times as great as that of gun-metal; and this, looked at alone, would appear to sanction the high value attributed to the first, as the best material for artillery; but when we examine the sixth column, in which the "work done" in overcoming the resistance of column 4, through the space due to the angle of torsion, is given, we find the startling result, that this is greater for wrought-iron, and even for the best gun-metal, than for the best cast-steel. Nothing can more clearly show the unfitness of steel, and the extreme suitability of soft wrought-iron, for making cannon.

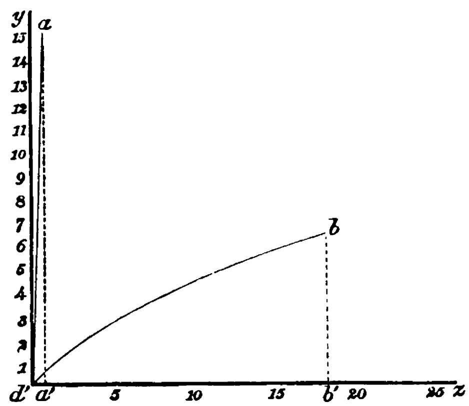
The cast-iron in this Table must have been extremely hard, probably a

mottled and nearly white iron, of very coarse grain, as the angle of torsion is so small, 12°; indeed the Report states, rather oddly, that it yielded "without extension" in the experiments of direct tension. This produces a value of T_r too small to truly represent cast-iron.

144. It might appear doubtful, how far values for the coefficient T_r, can be properly deduced from experiments on torsion. The proportionality of the numbers, however, is certain, as Cauchy has shown (Exerc. de Math., 4[e] anné) that in prisms exposed to torsion the constant G, or modulus of torsion, bears a constant relation to that of elasticity for any given material, or

$$G = \tfrac{2}{5}\,\epsilon.$$

145. Habit, and an uninstructed mode of viewing such questions, have produced the prevalent notion, of the *brittleness* of *cast*-iron, as contradistinguished from the *toughness* of *wrought*-iron. The fact is, cast-iron, within the range of four or five tons tension per square inch, is a much more ductile material than wrought-iron; its total extension per ton per unit of section, is far greater, and the "work done" in producing the extension for the first few tons (up, in fact, to the very limited strain, about 7 tons, at which rupture occurs), is much greater than in wrought-iron; and were it not that, the ultimate safe strain upon wrought-iron, is so much higher, cast-iron would be the better material for ordnance. But wrought-iron has a far greater ultimate cohesion—in about the ratio of 20 to 6—than cast-iron, and its softer varieties, a long and uniform range of extension; it is, therefore, in the exact sense of the word, the *toughest* material we are as yet acquainted with, and therefore the best, for artillery.



146. This peculiar property of cast-iron is evident from the accompanying diagram; in which, from the origin d', the ordinate $d'y$ is that of strain, and the abscissa $d'z$ that of extension; the curve a, that for wrought-iron, and b that for cast-iron; half the quadratures of the curves, $d'aa'$, $d'bb'$ being the work done to produce them in each case, the latter being obviously greatly in excess of the former.

147. The extensions, for each ton of load, up to 15 tons, when wrought-iron begins to lose form, and its elasticity to be permanently impaired, may be compared in the following Table, deduced from Professor Hodgkinson's experiments:—

TABLE VIII.

Total Extensions in proportion to L.

Tons.	Wrought Iron.	Cast-Iron.	
1	·0000689	·01976	
2	·000156	·01155	
3	·000238	·06515	
4	·000319	·09274	
5	·000399	·12397	
6	·00048	·16363	NOTE.—The cast-iron of these experiments was gray metal, and much inferior in tenacity to the mottled metal suitable for guns.
7	·00056	·18297	
8	·00064	Rupture.	
9	·00072		
10	·00080		
11	·000896		
12	·00102		
13	·00128		
14	·00231		
15	·00416		

148. It is not a little remarkable that the Yorkshire and Staffordshire cast-irons, which long experience has shown to be so valuable for gun-founding, possess by no means high coefficients of ultimate strength, while they *are* remarkable for their great extensibility and ductility. So prominent is this in Low Moor cast-iron, that it receives deeply the mark of the hammer, when struck cold, and possesses a certain amount of malleability, like an extremely soft and "over-worked" wrought-iron; and there can be no doubt, that it is the latter property, upon which its great value for cannon rests. The ultimate tensile strength of Low Moor and of Bowling cast-iron, is only 5·667 tons, and 6·032 tons respectively; while that of many other "makes" ranges from 7 up to 10·477 tons per square inch, and that of various mixed irons still higher.

149. It is not, therefore, by looking for foreign cast-irons (however smelted or procured), with great ultimate cohesion alone (to which the views of those "in authority" appear to be limited), that a better material of this class, than we at present possess, can be obtained; but by seeking that, which shall possess *such*

a combination of tensile strength and elastic range together, as shall give the highest value to the coefficients T_e and T_r. How little this may be expected from the continent of Europe, in preference to the productions of Great Britain, may be judged of by the following Table IX., compared with subsequent ones. The measures are generally below those assigned by British authors.

TABLE IX.

ULTIMATE COHESION *at Rupture, according to Continental Authors, in English Weights and Measures.*

		lbs. per square inch.	
Cast-steel, tilted,	Highest, ...	142222	Poncelet.
	Mean, ...	88657	Poncelet.
Wrought-iron, . .	Forged bars, highest,	75335	Karsten.
	„ „ mean, .	56889	Karsten.
	Boiler-plate in the direction of lamination,	58314	Navier.
	Boiler-plate, transverse to it, . . .	51200	Navier.
	Iron wire, ·0091 in diameter, highest, . .	128000	Ardant & Dufour.
	Iron-wire, ·039 in diameter, mean, . .	75000	Ardant & Dufour.
Cast-iron, . . .	Highest, ...	19201	Karsten.
	Lowest, ...	17782	Karsten.
Gun-metal, . .	Mean, ...	32704	Poncelet.*
Brass, ...	Wire hard from the draw-plate, mean under ·039 in. diam.,	71100	Ardant & Dufour.
	According to Rennie (Phil. Trans.), cast,	17920	

Mr. G. Rennie's result for gun-metal is, doubtless, greatly below the truth, yet his are almost the solitary experiments published up to this date on the strength of this widely used material for cannon. In contrast with the figures of Ardant and Dufour, it forcibly shows the effect of molecular arrangement on cohesion, and is given chiefly with that view.

150. I shall conclude this branch of the subject with Table X., in which all the conditions, as respects elasticity and extensibility, of the several materials for ordnance are presented together, the data being from continental experiments:—

* This agrees nearly with the American Government experiments. See "Report on Properties of Metals for Cannon." By authority of Secretary at War. Philadelphia, 1856; and Note N.

TABLE X.

RESISTANT Vis Viva, *of Elasticity and of Rupture by Tension of the Metals applicable to the Construction of Ordnance.*

Number.	METAL.	i Extension per unit of length up to elastic limit.	$T=P$ Strain per unit of section at elastic limit.	P Strain in Tons.	$T_e = \frac{1}{2}Pi$ Value for unit of length and section.	T_r Value for unit of length and section.	e Coefficient of elasticity for unit of section.
			lbs.		Dynams.	Dynams.	lbs.
1	Cast-steel (English), blue temper, .	·00022	47040	21·0	5·175	39·650	42·666·750
2	Cast-steel (German), soft, . . .	·00096	35392	15·8	16·988	103·500	28·866·725
3	Wrought-iron bar (maximum ductility), ...	·00090	17024	7·6	7·660	96·000	25·000·000
4	Wrought-iron (mean strength and ductility), ...	·00066	15232	6·8	5·026	64·075	28·444·500
5	Wrought-iron bar, strong and rigid,	·00054	25760	11·5	6·955	38·325	28·444·500
6	Cast-iron, mean, ...	·00085	14112	6·3	5·997	12·287	17·066·700
7	Gun-metal, cast, mean, ...	·00104	10304	4·6	5·308	93·525	9·955·575
8	Brass wire, drawn and softened, .	·00135	21280	9·5	16·490	31·680	9·173·190
9	Brass, cast, mean, ...	·00076	6944	3·1	2·639	20·900	8·930·000

No. 1, From Morin's experiments on flexure of dynamometric springs.
No. 2, From Morin's and Poncelet's Tables; but the value of i is probably greatly too high.
No. 8, From Ardant's experiments on fine brass wire, and require to be taken with reserve.

151. On examining this Table, the importance of holding in view the value of T_e and T_r, rather than the mere static strain, or that from a passive load, as respects the construction of artillery, becomes very striking. Thus, in the case of tempered cast-steel, although the resistance to a passive strain is taken as high as 21 tons per square inch, yet, from the extremely small range of extension, the "work done" to bring it to the limit of its safe load is found to be less than that required for soft ductile wrought-iron, that will only bear a passive load of about one-third as much as the steel, in the ratio of 5·175 : 7·660. So also by the comparison between the soft ductile iron No. 3, and the much stronger (to a passive strain), but less extensible, iron, No. 5: the "work done" in the former at the elastic limit being 7·660 : 6·955 in the latter. Again, it will be remarked, that, although so much weaker, in mere tenacity, under passive strain, than wrought-iron, yet, from the far greater extensibility of cast-iron (No. 5), the "work done" to bring it up to its elastic limit, is actually greater than that of wrought-iron of mean quality (No. 4), in the ratio of 5·997 : 5·026; while, lastly, we may remark that gun-metal, with a tenacity at the elastic limit a third under that of cast-iron, requires nearly as much "work done" by a dynamic effort, to bring it to that point.

152. It is easy, then, to understand, how widely mistaken have been the estimates of Mr. Nasmyth* and others, as to the comparative resistances, of wrought and of cast-iron, for ordnance, in assuming the former at six times the strength of the latter.

Much more extended experimental information is yet needed, however, to bring these conditions into a state to be applied with perfect assurance, in calculation and practice.

19.—*Gun-Metal or Bronze as a material for Cannon.*

153. We have already considered some of the physical properties of gun-metal in relation to the other materials for cannon, in treating of the effects of unequal expansion by heat; but in order fully to compare the relative values of the four great classes of materials, for the construction of ordnance, viz., cast-iron, wrought-iron, steel, and gun-metal, it is necessary to treat more at length of the physical, and especially, the chemical properties of the latter alloy. Gun-metal, probably the very earliest used material for cannon, is that which has received the least improvement or systematization of our knowledge as to its use, up to the present hour,—the archæologist finds the rude weapons of Scandinavian, Celtic, Egyptian, Greek, and Roman warfare, formed of nearly the same alloys of copper and tin, and in about the same proportions, as the cannon of to-day.†

This has resulted, not from total neglect of the subject, nor from insuperable difficulties, but because a result, considered "good enough" in practice, has been arrived at, in the chief gun-foundries of Europe long since, and because whatever experiments have been undertaken to improve (so far as any such have been published) have proceeded with little system, and in the hands of men, not possessing the indispensable qualifications for success, namely, an accurate and extensive acquaintance, with both chemical metallurgy, and physics, on the one hand; and with the demands of the artillerist, and the practical devices, experiences, and skill of the founder, upon the other.

Such an inquiry remains still to reward the labour, and well-directed knowledge, that shall be bestowed upon it, and should gun-metal always continue to

* See Mr. Nasmyth's letter to "The Times," November, 1854.

† See Dr. J. W. Mallet's "Chemical Enquiry into the Metallic Antiquities of the Royal Irish Academy Museum." Trans. R. I. A., vol. XXII.

form the staple material for field artillery (which, however, appears by no means probable), it would be an object worthy of national undertaking and expenditure, as being utterly beyond the reach of private effort, or the demands of commerce.

154. The circumstances of chief difficulty and importance, in the manipulation of gun-metal, as affecting the production of cannon, are:—

1°. The chemical constitution of the alloy, as influencing the balance of its hardness, or $\frac{\text{rigidity}}{\text{ductility}}$, and tenacity.

2°. Its chemical constitution, and what other conditions, influence the segregation, of the cooling mass of the gun when cast, into two or more alloys, of different and often variable constitution.

3°. The effects of rapid and of slow cooling, and of the temperature at which the metal is fused and poured.

4°. The effects due to repeated fusions, and to foreign constituents, in minute proportions entering into the alloy.

155. These questions have been more or less considered by Antoni, Biringoccio, Briche, Dartein, Schlié, Lamartilliere, Monge, Darcet, Andreossi, Dussaussoy, Gay-Lussac, Moriz Meyer, De Massas, and others, but by none systematically.

156. Omitting the older guns, which almost always consisted of a heterogeneous mixture of copper and tin, with zinc, lead, antimony, cobalt, nickel, silver, and iron, or one or more of these; all modern gun-metal comes to be some particular case of the general formula $(Cu_x + Sn_y)$.

157. The following Table, extracted from the author's Second Report on Iron (Trans. Brit. Assoc., vol. IX.), contains the results of a carefully conducted series of experiments made by him on the chemical constitution and physical properties of a number of such binary alloys. A few additions have been made of alloys, remarkable or important in their mercantile, or other relations, so far as their properties have been ascertained.

It is astonishing to find that, after five hundred years' habitual use of the material, the military literature of Europe appears barren of a single series of systematized and accurate experiments on the physical properties of gun-metal. Nor has America produced such, although in advance, by the skill and energy devoted to the improvement of its ordnance, which its numerous Government Reports display.

Table XI.

Showing *the Physical Properties of the Atomic Alloys of Copper and Zinc, and of Copper and Tin.*

1	2	3	4	5	6	7	8	9	10	11	12	13
No. of Experiment.	Chemical Constitution. ε − + ε −	Composition by weight per cent. ε − + ε +	Atomic Weight. $H = 1$	Specific Gravity.	Colour of Fracture.	Fracture.	Ultimate Cohesion per square inch.	Inverse order of Ductility.	Order of Malleability, at 60° Fahr.	Inverse order of Hardness, &c.	Inverse order of Fusibility.	Commercial Titles. Characteristic Properties in Working, &c.
					COPPER AND ZINC.							
							Tons.					
1	Cu —	100·00 + 0	31·6	8·667	Tile-red.	E.	24·6	8	1	22	15	Copper.
2	10 Cu + Zn	90·72 + 9·28	348·3	8·605	Reddish-yellow, 1	C.C.	12·1	6	13	21	14	
3	9 Cu + Zn	89·80 + 10·20	316·7	8·607	Reddish-yellow, 2	F.C.	11·5	4	11	20	13	
4	8 Cu + Zn	88·60 + 11·40	285·1	8·633	Reddish-yellow, 3	F.C.	12·8	2	10	19	12	Similor, &c., { Several of these are malleable at high temperatures.
5	7 Cu + Zn	87·30 + 12·70	253·4	8·587	Reddish-yellow, 4	F.C.	13·2	9	9	18	11	
6	6 Cu + Zn	85·40 + 14·60	221·9	8·591	Yellowish-red, 3	F.F.	14·1	5	8	17	10	
7	5 Cu + Zn	83·02 + 16·98	190·3	8·415	Yellowish-red, 2	F.C.	13·7	11	2	16	9	Bath metal.
8	4 Cu + Zn	79·65 + 20·35	158·7	8·448	Yellowish-red, 1	F.C.	14·7	7	3	15	8	Dutch Brass.
9	3 Cu + Zn	74·58 + 25·42	127·1	8·397	Pale yellow,	E.C.	13·1	10	4	14	7	Rolled sheet Brass.
10	5 Cu + 2 Zn	71·43 + 28·57	222·6	?	. . . .	. . .	. .	. .	. .	. .	. .	Normal Brass.
11	2 Cu + Zn	66·18 + 33·82	95·5	8·299	Full yellow, 1	F.C.	12·5	3	6	13	6	British Brass.
12	19 Cu + 12 Zn	60·00 + 40·00	988·0	8·200	Full yellow.	C.	1·9	1	3	15	6	Muntz patent sheathing.
13	Cu + Zn	49·47 + 50·53	63·9	8·230	Full yellow, 2	C.C.	9·2	12	5	12	6	German Brass.
14	Cu + 2 Zn	32·85 + 67·15	96·2	8·283	Deep yellow.	C.C.	19·3	1	7	10	6	„ Brass, Watchmakers'.
15	8 Cu + 17 Zn	31·52 + 68·48	801·9	7·721	Silver-white, 1	C.	2·1	0	22	5	5	Very brittle,
16	8 Cu + 18 Zn	30·30 + 69·70	834·2	7·836	Silver-white, 2	V.C.	2·2	0	23	6	5	Very brittle,
17	8 Cu + 19 Zn	29·17 + 70·83	866·5	8·019	Silver-gray, 3	C.	0·7	0	21	7	5	Very brittle, } Too hard to file or turn, lustre nerly equal to Speculum metal.
18	8 Cu + 20 Zn	28·12 + 71·88	898·8	7·603	Ash-gray, 3	V.	3·2	0	19	3	5	Brittle,
19	8 Cu + 21 Zn	27·10 + 72·90	931·1	8·058	Silver-gray, 2	C.	0·9	0	18	9	5	Brittle,
20	8 Cu + 22 Zn	26·24 + 73·76	963·4	7·882	Silver-gray, 1	C.	0·8	0	20	8	5	Very brittle,
21	8 Cu + 23 Zn	25·39 + 74·61	995·7	7·443	Ash-gray, 4	F.C.	5·9	0	15	1	5	Barely malleable..
22	Cu + 3 Zn	24·50 + 75·50	128·5	7·449	Ash-gray, 1	F.C.	3·1	0	16	2	4	Brittle.
23	Cu + 4 Zn	19·65 + 80·35	160·8	7·371	Ash-gray, 2	F.C.	1·9	0	14	4	3	White Button metal.
24	Cu + 5 Zn	16·36 + 83·64	193·1	6·605	Very dark-gray.	F.C.	1·8	0	17	11	2	Brittle.
25	— Zn	0 + 100·00	32·3	6·895	Bluish-gray.	T.C.	15·2	13	12	23	1	Brittle, Zinc.
					COPPER AND TIN.							
1	Cu +	100·00 + 0	31·6	8·667	Tile-red.	E.	24·6	1	2	10	16	Copper.
2	10 Cu + Sn	84·29 + 15·71	374·9	8·561	Reddish-yellow, 1	F.C.	16·1	2	6	8	15	Gun-metal, &c.
3	9 Cu + Sn	82·81 + 17·19	345·3	8·462	Reddish-yellow, 2	F.C.	15·2	3	7	5	14	Gun-metal, &c.
4	8 Cu + Sn	81·10 + 18·90	311·7	8·459	Yellowish-red, 2	F.C.	17·7	4	10	4	13	Gun-metal, tempers best.
5	7 Cu + Sn	78·97 + 21·03	280·1	8·728	Yellowish-red, 1	V.C.	13·6	5	11	3	12	Hard mill Brasses, &c.
6	6 Cu + Sn	76·29 + 23·71	248·5	8·750	Bluish-red, 1	V.	9·7	0	12	2	11	Brittle,
7	5 Cu + Sn	72·80 + 27·20	216·9	8·575	Bluish-red, 2	C.	4·9	0	13	1	10	Brittle,
8	4 Cu + Sn	68·21 + 31·79	185·3	8·400	Ash-gray.	C.	0·7	0	14	6	9	Crumbles,
9	3 Cu + Sn	61·69 + 38·31	153·7	8·539	Dark-gray.	T.C.	0·5	0	16	7	8	Crumbles, { All these Alloys found occasionally in Bells, and Specula with mixtures of Zn. and Pb.
10	2 Cu + Sn	51·75 + 48·25	122·1	8·416	Grayish-white, 1	V.C.	1·7	0	15	9	7	Brittle,
11	Cu + Sn	34·92 + 65·08	90·5	8·056	Whiter still, 2	T.C.	1·4	0	9	1	6	Small bells, brittle,
12	Cu + 2 Sn	21·15 + 78·85	149·4	7·387	Whiter still, 3	C.C.	3·9	0	8	1	5	„ brittle,
13	Cu + 3 Sn	15·17 + 84·83	208·3	7·447	Whiter still, 4	C.C.	3·1	0	5	1	4	Speculum metal of Authors.
14	Cu + 4 Sn	11·82 + 88·18	267·2	7·472	Whiter still, 5	C.C.	3·1	8	4	14	3	„ Files, tough.
15	Cu + 5 Sn	9·68 + 90·32	326·1	7·442	Whiter still, 6	E.	2·7	6	3	15	2	„ Files, soft and tough.
16	+ Sn	0 + 100·00	58·9	7·291	White, 7	F.	2·5	7	1	16	1	Tin.

Abbreviations used in Column 7 to denote character of Fracture:—F.C. Fine Crystalline, C.C. Coarse Crystalline, T.C. Tabular Crystalline, F.F. Fine Fibrous. C. Conchoidal, V.C. Vitreo-Conchoidal, V. Vitreous, E. Earthy.

The maxima of Ductility, Malleability, Hardness, and Fusibility, are = 1.

The numbers in Column 6 denote intensity of shade of the same colour.

The Atomic Weights are those of the Hydrogen Scale.

The Specific Gravities were determined by the method indicated in Report, Trans. Brit. Ass. vol. vii., p. 283.

The Ultimate Cohesion was determined on prisms of 0·25 of an inch square, without having been hammered or compressed after being cast. The weights given are those which each prism just sustained for a few seconds before rupture.

The Copper used in these Alloys was granulated, and of the finest "Tough Pitch:" the Zinc was Mosleman's, from Belgium; and the Tin "Grain Tin," from Cornwall. They were alloyed in a peculiar apparatus, to avoid loss by oxidation, and the resulting alloy verified by analysis.

No simple Binary Alloy of Cu + Zn or of Cu + Sn works as pleasantly in turning, planing, or filing, as if combined with a very small proportion of a third fusible metal, generally $(Cu + Zn)^n + Pb$; or $(Cu + Sn)^n + Zn$, as is known to workers in metals. Statuary Bronzes are all Ternary or Quaternary Compounds, as are also most old cannon, from the accidental introduction of foreign metals.

No 8, 4 Cu + Sn, is Lord Rosse's Speculum Metal, which would appear to gain brightness of colour and lustre by his method of chill-casting, and by increase of mass.

158. In gun-metal, as in every other material for cannon, while sufficient hardness must be secured to resist longest, the abrasion of shot, and the deflagration of the powder, along with the greatest ultimate tenacity, there must be such a balance, of rigidity and ductility with ultimate cohesion, as shall give the maximum value to the coefficients T_e and T_r.

The hardness and rigidity increase with the proportion of tin ; the ductility and tenacity with that of the copper, but not in any direct ratio in either case.

159. The specific gravity increases with the copper generally, although M. Briche's statements (Jour. des Min. t. v.) indicate the contrary:—

Cu + Sn.	Sp. Gr. *actual.*	Mean Sp. Gr. *calculated.*
100 + 4	8·79	8·74
100 + 6	8·78	8·71
100 + 8	8·76	8·68
100 + 10	8·76	8·66
100 + 12	8·80	8·63
100 + 14	8·81	8·61
100 + 16	8·87	8·60
100 + 33	8·83	8·43
100 + 100	8·79	8·05

On this Dumas has remarked, that the true density is masked by the effects of various forms of aggregation in the different alloys. The increase of density, however, is certainly towards the copper, though in no ascertained ratio to the decrease of tin. The fusibility is always greater than that of copper, less than that of tin. The ultimate cohesion is always less than that of the best refined tough copper, but greater than that of tin. The ductility less than that of copper, greater than that of tin. The hardness always greater than that of either.

160. Few examples are met with, of guns formed of metal in strictly atomic proportion, but alloys are therein found, presenting every formula, from (7 Cu + Sn) up to (83 Cu + 4 Sn). The proportions most approved of in the arsenals of Europe appear to vibrate between 100, by weight, of copper to 9 of tin, up to 100 of copper to 12 of tin. In France, 100 copper + 11 tin, by weight, is the proportion fixed by law, invariably aimed at, and, we shall see reason to conclude, judiciously so. In the United States 100 copper + 12·5 tin is adopted for certain species of guns.

161. In common with the great majority of metallic alloys, gun-metal is held

so loosely in combination, that very slight forces are sufficient to induce its segregation, into two or more different alloys, which, on cooling, are found to occupy different portions of the mass, and possibly even to separate a portion of one or other of the constituent metals.

162. Thus, in a gun cast vertically, and permitted to cool slowly, as in the ordinary practice of " loam casting," the external portions, which cool first, have a determinate constitution, different from that assigned by the proportions of the metals, as fixed for fusion. The interior of the gun, which cools last, has another constitution different from either, and always richer in tin. But when the whole gun has become solid, and portions are examined, from the extreme lowest, middle, and highest parts, of the previously fluid column of metal, it is found that these again differ from each other, and that this difference varies, in the vertical for the exterior or crust alloy, which has cooled first, and for the interior column of alloy that has cooled last; so that, in fact, of any gun, no two adjacent portions have strictly the same chemical constitution,—the maximum of copper being found in the exterior and breech of the gun, or lowest part of the column of metal; and the maximum of tin, in the interior and highest part of the metallic column. The utmost discordance prevails in authors as to the position in the gun in which the maximum of tin is found; their conclusions being almost always based upon isolated facts, and taking no account of the differences that must arise from variations in the primary alloy, and in the details and circumstances of its moulding, casting, and cooling, difference of mass, &c.

The account given must be viewed as the normal case, in which the homogeneous alloy is subjected to no forces in consolidating but those of its own affinities, of gravitation and of cooling by radiation in a perfectly equable manner.

163. The segregation from the exterior to the interior is due to a play of chemical affinity, separating the whole mass into two or more definite atomic alloys, that of the exterior possessing less fusibility, and more copper, than that in the interior, which remains fluid longer.

The constitution of the latter was found by Dussausoy, to approach in almost every case, an average constitution of (8 Cu + Sn).

164. The phenomena that attend its separation are remarkable. Some time after the exterior of the gun has become solid, the still liquid interior of the column of metal begins to present, at its upper extremity, intestine motions, often attended with sputterings and jets of metal, and ending, by the upper extremity rising more or less above its former limit, in an irregular fungoid form, and then becoming solid. This has usually been ascribed to a change of volume occurring in the mass of the internal alloy at the moment of its consolidation, due to crystalline or other molecular forces, while the sputtering and jets of metal, and the cauliflower-like top assumed by the upper end of the column of metal (the top of the "rising head," or "dead head" of the gun-founder) has been ascribed to the escape of air from the mould, through the still liquid metal of the interior,—an attempt at explanation certainly erroneous (though copied almost word for word from author to author), since any air requiring escape, from the sides of the loam mould, would commence to escape through the column of metal, if escaping at all through it, the moment the mould was full, when the metal is *all* hottest and most fluid, and could not possibly escape through the central fluid portion of the mass subsequently, to the consolidation of the exterior, and, indeed, in no case of moderately good moulding need, or can escape, either way, other channels being provided for it. The true cause of the phenomena seems to be this.

165. Copper, like silver, possesses, in all probability, the property of absorbing oxygen when in fusion, and its alloy with tin does not appear to prevent this, contrary to the case of silver, wherein a slight alloy of copper is sufficient to prevent its absorption of oxygen, which Lucas discovered was absorbed by pure silver in fusion to the extent of twenty times its own volume; the metal evolving the whole of it again at the moment of consolidation by cooling, and with the protrusion of similar fungoid masses, which present themselves like little craters on the surface of a large ingot of refined silver.

Direct experiment has not yet, the author believes, shown a like absorption of oxygen by copper or its alloys with tin; but that the fact is so, is indicated by several circumstances. Copper possesses the utmost susceptibility to absorb many other bodies while in fusion; thus the well-known process called "poling," of refining "tile copper," which is short, brittle, and incapable of being beaten out, laminated, or wire-drawn, to bring it to "tough pitch," when it admits

of all these, consists in stirring up the mass of melted metal with a dry, hard-wood stick. What occurs seems to be the removal of a portion of oxygen, either directly combined, or in the state of a combined suboxide, from the mass, by the affinity of the hydro-carbons produced by the burning of the wood beneath the molten mass. When this process is carried too far, the copper, in place of remaining at "tough pitch," at which, when cold, it would be capable of being forged, rolled, wire-drawn, &c., "goes back," and becomes brittle and short as "tile copper" again; and on examination it is found now, that the oxygen is gone, but that it is replaced by a small proportion of carbon, which the metal has absorbed. Oxygen is, therefore, present in the metal, but a slight play of affinities is sufficient to cause its removal from the liquid metal, from which some, at least, is probably evolved on its consolidation otherwise. But it is a fact well known to gun-founders and bell-founders that the oftener the alloys of copper and tin are melted, the more difficult it is to produce solid castings with them, and that very frequently castings made with such metal, though presenting no large or obvious cavities or defects, are yet found, upon examination with the microscope, to be filled, almost with perfect uniformity, throughout the whole mass, with innumerable minute vesicles, all of an almost perfectly spherical form. In the case of large bells this is not uncommon; and the author, in his own practice, once examined a bell of large weight, cast chiefly from old bell-metal, so filled with vesicles of this sort that the want of homogeneity, interfered with the sonoricity of the metal, and the bell gave scarcely any clear sound when struck, and was, moreover, unusually brittle and incoherent.

Now, it is an ascertained fact that this difficulty of making sound castings from old and often re-melted alloys of copper with tin (or with zinc) arises from the oxidation of the tin and the copper, which the experiments of Dussausoy showed, took place in such proportions that in the case of gun-metal, for one part by weight of tin oxidated, from three to four of copper were so. A part of this oxygen absorbed or combined appears, then, to be given up again by one or by both metals at the moment of consolidation, and *its* evolution to be the cause of the perfectly uniform dissemination of the minute air-vesicles alluded to, which are seldom known to occur in such abundance in new or not frequently fused metals, though more or less, they may almost always be found by microscopic examination, of all gun and bell-metals.

But again, where copper, or its alloys, have absorbed an excess of carbon,

as already noticed, it is not improbable that the latter, at the high temperature of fusion, may, in the processes of fusion, pouring, &c., combine with oxygen from the atmosphere, and give rise to the vesicular structure by the evolution of volatile matter, such as carbonic oxide, within the mass. The combination, like the absorption of oxygen, taking place at a higher temperature, and the subsequent evolution at a lower and definite one, at which the affinity of the copper, or its alloy, for either the absorbed oxygen, or the absorbed carbonic oxide, is a minimum.

While, therefore, increase of volume *may* occur in the central mass of the more fusible alloy of the gun, owing merely to some changes of molecular arrangement at the instant of its consolidation, (in accordance with many analogous cases), the whole increase, does not appear due to this, but also to the sudden evolution of gaseous matter (oxygen, or its compounds, with carbon) derived from the oxides or from absorbed oxygen and carbon within the mass, at the moment of consolidation, and the sudden elastic evolution of part of which, at the head of the casting, causes the sputtering, &c., already described.

166. The constitution of the alloy changes, not only in the cooling, but in the melting, by the continual reduction of the quantity of tin, which oxidates much faster than the copper, though the latter be present in so much greater mass. Dussausoy found that gun-metal having the proportions of 100 copper and 11 tin, by weight, had the following constitutions after each of six consecutive meltings, indicating the rapidity with which oxidation of the tin occurs:—

	Resulting Constitution of Alloy.		
Fusions.	Copper.		Tin.
1, ...	100·3	+	10·7
2, ...	100·7	+	10·3
3, ...	101·8	+	9·2
4, ...	103·0	+	8·0
5, ...	104·0	+	7·0
6, ...	105·5	+	5·5

The extreme irregularity of the specific gravities that he gives attached to each, prove the extent to which the oxides become involved in the mass, and the latter is rendered "boursoufflé" thereby. It is probably in virtue of the reduction again of these disseminated oxides, by an elevated heat, that the opinion

of M. Briche, of the Gun-foundry at Strasbourg, is founded (Journal des Mines, tom. vi., an. v. de la Republique)—namely, that the higher the temperature to which the melted mass is exposed, the more uniform is the metal when cast. Experiments made in the United States in 1850 render it extremely probable that the evolution of gaseous matter, referred to (see 164, 165), occurs chiefly within the limits of a very high range of temperature, which corroborates the explanation here offered of the phenomena. These experiments also showed that the best results were obtained from castings "poured" at a low temperature, though still a determinate one, beneath which they again deteriorated. This, however, does not conflict with the view that a very high temperature *of fusion may* be advantageous, although analogy renders it improbable. At the best temperature in the American experiments there was no fungoid excrescence driven up over the "rising head," and the large and uniform contraction of the latter in cooling, indicated the great density which the gun-metal was subsequently found to possess.

167. Whatever be the immediate causes determining the segregation of the normal alloy, the separation in any gun-metal having the general formula $(Cu_x + Sn_y)$ may take any one of three forms, namely—

$$(Cu_{x'} + Sn_{y'}) + Cu_z;$$
$$(Cu_{x'} + Sn_{y'}) + Sn_z;$$
$$(Cu_{x'} + Sn) \quad + (Cu + Sn_{y'});$$

or more than one of these together.

168. Alloys, of precisely definite atomic proportions, generally present the best pronounced and most constant physical properties. It has been doubted, however, whether this be so in the case of the gun-metals, the very best of which are found within the limits (given in the preceding Table VII.), viz., between 9 and 12 by weight of tin to 100 of copper.

On examining more closely the atomic constitution of these four alloys, however, we shall find reason to adhere to the conclusion, that the most definite alloy makes the best gun-metal ; and to remark that the curious segregation into two or more different, but still definite alloys, is probably intimately concerned with its toughness and elasticity ; that, in fact, the gun, with the central portions so rich in tin bored out, consists of a comparatively soft and

ductile alloy, embracing in a state of extreme comminution throughout its mass, another harder and more elastic one; and thus singularly analogizing with the constitution of the best cast-iron for gun founding; the mottled (*fonte truité*), of which we have already treated, which consists throughout its mass, as stated, of a soft, minutely graphitic iron, embraced by a disseminated, hard, white, and lamellar metal, whose carbon is all chemically combined. Thus:—

	Cu + Sn	Composition per Cent.	Divided by Atomic Weights.	Atomic Constitution.
		Cu Sn		
1	100 + 9	91·743 + 8·257	2·903 + ·1401	20·72 Cu + Sn
2	100 + 10	90·909 + 9·091	2·876 + ·1543	18·64 Cu + Sn
3	100 + 11	90·090 + 9·910	2·851 + ·1682	16·95 Cu + Sn
4	100 + 12	89·285 + 10·715	2·825 + ·1819	15·52 Cu + Sn

These in whole numbers approach nearest to—

	Atomic Constitution.	Composition per Cent.	Atomic Weight.
		Cu + Su	
1	83 Cu + 4 Sn	91·58 + 8·42	2798·4
2	56 Cu + 3 Sn	91·12 + 8·88	1946·3
3	17 Cu + 1 Sn	90·12 + 9·88	596·1
4	31 Cu + 2 Sn	89·27 + 10·73	1097·4

We thus find that the gun-metal No. 3, consisting of 100 copper + 11 tin (which, after repeated trials and long experience, was fixed by Statute in Oct., 1769, as the only alloy to be used for French cannon, having been found the best), has in reality a very simple and almost precise atomic constitution; for the small excess per cent. in tin, as put into the furnace, namely, the difference between 9·910 and 9·880 per cent., will be just about eliminated in the alloy by oxidation in melting, leaving the gun-metal almost precisely 17 Cu + Sn, and most probably this more stable alloy is the basis of several others above and below it in the scale.

169. The exuded alloy from the centre of the mass was found by Dussausoy to have the constitution (Cu_8 + Sn), or, as he says, an atom above or below, in copper, which, on referring back to Table x., is, we find, the harder and more elastic of the two,—we can then deduce the following rational formulæ as

representing some of the more probable forms of constitutional arrangement of the whole mass, in each of the four preceding alloys, after consolidation.

No. 1. 100 : 9 $= 83\,Cu + 4\,Sn$
$= 4\,(Cu_{17} + Sn) + Cu_{15}$
$= 3\,(Cu_{17} + Sn) + (Cu_8 + Sn) + Cu_{24}$
$= 3\,(Cu_{17} + Sn) + 0{\cdot}5\,(Cu_{48} + Sn) + 0{\cdot}5\,(Cu_{16} + Sn)$
$= 2\,(Cu_{34} + Sn) + 2\,(Cu_7 + Sn) + Cu.$

No. 2. 100 : 10 $= 56\,Cu + 3\,Sn$
$= 3\,(Cu_{17} + Sn) + Cu_5$
$= 2\,(Cu_{17} + Sn) + (Cu_8 + Sn) + Cu_{14}$
$= (Cu_{34} + Sn) + (Cu_{17} + Sn) + (Cu_4 + Sn) + Cu$
$= (Cu_{51} + Sn) + 0{\cdot}5\,(Cu_8 + Sn) + 0{\cdot}5\,(Cu_2 + Sn).$

No. 3. 100 : 11 $= 17\,Cu + Sn.$ (Normal gun-metal.)

No. 4. 100 : 12 $= 31\,Cu + 2\,Sn$
$= (Cu_{17} + Sn) + (Cu_8 + Sn) + Cu_6$
$= (Cu_{17} + Sn) + (Cu_{12} + Sn) + Cu_2$
$= (Cu_{17} + Sn) + 0{\cdot}5\,(Cu_{16} + Sn) + 0{\cdot}5\,(Cu_{12} + Sn)$

Analyses quoted by Moritz Meyer, of the Russian service, and verified in France by Ravichio de Peretsdorf, proved the segregated alloy in many cases to have the constitution ($6\,Cu + Sn$), an alloy as hard as bell-metal. (See Table x. 6.)

Applying this to the empiric formula No. 1, we obtain such rational formulæ as the following:—

$$
\begin{aligned}
& 83\,Cu + 4\,Sn \\
= {} & 3\,(Cu_{17} + Sn) + (Cu_6 + Sn) + Cu_{26} \\
= {} & 2\,(Cu_{17} + Sn) + (Cu_{34} + Sn) + (Cu_{12} + Sn) + Cu_3 \\
= {} & (Cu_{68} + Sn_3) + (Cu_{15} + Sn).
\end{aligned}
$$

All which agree with the former in this, that the total compound is broken up into two or more alloys, the copper in one of which (normal gun-metal, $17\,Cu + Sn$) bears to that of any of the segregated alloys, the ratio of $17 : n \times 2$. These are incommensurable numbers; and hence the primary cause of segregation shows itself to consist, not in separation merely, through difference of specific

gravity, or of change of affinity with temperature, &c., but in the competency of copper and tin to form two sets of alloys, whose respective combining ratios are such as to render secondary combination in the alloys themselves impossible. It might be presumed that the addition in small proportion of a third metal, capable of combining with both alloys, would unite them, and improve the physical properties of the whole. This does not, however, seem to be indicated by the very numerous, though most desultory and unsystematic, trials of ternary alloys, made at various periods and places, numbers of which may be found recorded in the works of Hervé and of Meyer. The whole subject of bronze gun-casting and of the gun-metal is, as it were, yet to be investigated; and success can only attend this when, for the first time, it shall be commenced and pursued in a truly philosophical spirit, and with the full aids of Chemistry and Physics combined.

170. It is probable, therefore, that Nos. 1, 2, and 4, and many other gun-metals besides, consist when cast of the normal metal ($Cu_{17} + Sn$), with one or more subordinate alloys, exuded or not, and with or without a proportion of separated copper; in other alloys of different proportion, a similar segregation may occur, with separation of a portion of tin. But that there is no advantage gained necessarily, by mere complexity of constitution, is pretty obvious from the normal and simple alloy being found in practice the best; the only qualification being, that in French arsenals it is considered, that for small and light guns below nine-pounders, 100 copper + 8 tin is better, the alloy 100 copper + 11 tin being used for all above.

171. Where the atomic constitution is complex, and especially where the tin is in excess, the affinity of the alloy seems to reach its extreme of incoherence. Thus Berthier found that an alloy which had been found decisively defective in quality for guns, and which was submitted to him for analysis (Ann. des Mines, t. vii., 3ie ser.) had the composition—

Copper, ...	83·8
Tin, ...	15·7
Lead, ...	0·5

Neglecting the lead, as no doubt accidental, though most prejudicial to the qualities of the alloy, the composition of this metal approaches to 9·66

atoms of copper to 1·00 atom of tin, which would give rise to the rational formula—

$$58\,(Cu_{17} + Sn) + (Cu_8 + Sn) + (Cu_2 + Sn) + Sn_{40}.$$

There is, therefore, a large proportion of uncombined tin merely diffused through the mass (like water in a sponge), and the whole combination is held together, independently of this, in the very loose way that characterizes the alloys of all metals, in which the combining proportions demand large multipliers for the atoms of either or both metals; the general fact admitting of no exception, that the simplest and most elementary alloys, are those most firmly combined.

172. An extensive series of experiments made some years since by the author, upon the effects of additions in minute but atomic proportions, of various third metals to the binary alloy of copper and zinc, known as Muntz's metal (No. 10, Table x.) embracing antimony, lead, iron, bismuth, arsenic, and silver, proved that in every instance the ductility, tenacity, flexibility, and resistance to torsion were seriously impaired by proportions under even 1 per cent. These experiments were conducted upon a large scale, merchant sheathing sheets being rolled out from the alloy in each instance; they are, therefore, to be relied upon, and may probably be applied with like confidence to the binary alloys of copper and tin also, as indicating like results.

173. If it should appear that part of the tin of gun-metals separates *solely* in virtue of its greater fusibility and less specific gravity, and in *every* atomic constitution, the fact would seem to make vain any chemical consideration as to the proportions of these alloys, and make it doubtful that they were true chemical compounds at all; but though often loosely so stated, the fact seems in no instance ascertained to be so, and the specific gravities of the alloys, differing from the mean of their constituents, as well as all other facts, oppose the conclusion that such mere mechanical segregation of the tin alone, ever occurs with atomically proportioned alloys. Lamartilliere ("Researches sur l'Artillerie") mentions uncombined nodules of tin, as occasionally found segregated, and embedded in the interior of the mass of bronze guns. Nevertheless, it is extremely doubtful, that either tin or copper is ever segregated in a state of purity, i. e. unalloyed with each other, from any primary alloy between 100 : 9 and 100 : 12 by weight.

174. The alteration in constitution in the vertical direction, by which, when cold, there is more copper in the lower part of the column of the gun, appears to be due simply to the effects of gravitation acting upon the denser metal (the copper), and partially eliquating it from its extremely loose combination with the tin. It would be contrary to all chemical analogy to suppose that the increased statical pressure towards the base of the column acted in inducing the descent of the copper,—pressure tending usually to increase affinity and promote the stability of compounds,—unless, indeed, we presume that the affinity of tin for copper varies with pressure, and, as this increases, causes the tin of the lowermost parts of the column to rob copper from the superior portions of the mass. The simplest and first explanation seems the most probable. The fact, however, is certain. Thus, Dussausoy found that of a prism of gun-metal, of only 13 French inches high and 3 inches square, the copper varied between the extreme lower and upper ends in the ratio of 99·9 : 92·9.

175. From these two distinct modes of segregation of the alloy in vertical column, then it is obvious that, the "head of metal," above the intended muzzle of the gun, plays a very different part in cast-iron and in gun-metal guns; in the former, consolidating and condensing the crystalline mass by pressure only of the liquid head, but in the latter case not only doing this, but by extending the *total length* of the column of liquid metal, giving greater uniformity of composition to the segment cut off from the lower end to form the future gun. For it is obvious that with fixed limits of variation between the composition of the two extreme ends of the vertical column, the longer the column itself is, the less will be the total difference between the compositions of the extreme ends of any segment cut from it. It will, therefore, be good practice to extend to the utmost, in all cases, the " head of metal" (*matelotte*), or " dead head," above the upper part of the gun in the vertical mould.

176. The more slowly the column of metal cools, the more complete and injurious will be the process of segregation in the mass of alloy, and with the same methods of moulding, the cooling will be slower in proportion as the temperature of the metal poured into the mould is higher. The same general conclusion that we arrived at in the case of cast-iron guns applies, therefore, here, though for a different reason; *the lower the temperature at which the metal remains sufficiently fluid perfectly to fill the mould, the better will be the gun when*

cast; and this must be true, however well or ill founded M. Briche's opinion may be, of the advantage of a previous high temperature in the melting furnace to induce perfect combination of the metals.

177. The more rapidly, then, the mass can be cooled, the better. In the case of cast-iron guns we found this to be so likewise, but from the properties of that metal we cannot push it far; the case, however, is very different with gun-metal, where sudden cooling, as sudden as when the red hot mass is quenched in cold water, is attended with this singular and opposite result, that the metal is thereby rendered softer, tougher, and more malleable,—a discovery due to M. Darcet, and subsequently pursued and experimented on by Dussausoy, the results of some of whose researches are given in the following Table, showing the effects of this tempering (*trempe*) or sudden cooling, upon five principal alloys of copper and tin, embracing a large range.

No.	Composition by Weight.	Sp. Gr. before Tempering.	Sp. Gr. after Tempering.	Hardness before Tempering.	Hardness after Tempering.	TENACITY. In small pieces. Before	After.	In large pieces. Before.	After.
	Cu + Sn								
1	95 : 5	7·92	7·89	100	99	80	100	100	75
2	90 : 10	8·08	8·00	100	98	66	100	100	78
3	85 : 15	8·46	8·35	100	96	48	100	80	100
4	80 : 20	8·67	8·52	100	92	50	100	80	100
5	75 : 25	8·57	8·31	100	91	70	100	100	35

These results seem to indicate, that within the limits of the gun-metal proportions, sudden cooling does not injure, and may even increase the tenacity (absolute cohesion), and that probably it diminishes the density and the hardness of the alloy. Dussausoy indeed ascertained that the remarkable alloy ($Cu_8 + Sn$), which is exuded by gun-metals in consolidating, is that which is most improved by sudden cooling (*trempe*); that its tenacity is thus invariably *increased*, no matter what may be the mass or thickness of the casting. There are sufficient grounds for believing that where all the requisite conditions are attended to, increased density and tenacity, with homogeneity of composition, will result from the rapid cooling of gun-metal, whatever may be the mass of the castings.

178. As, therefore, in the casting of guns we may neutralize a diminution of density by increasing the statical pressure of the "head of metal," and can increase the hardness, by the addition of more tin, it seems well worthy of careful trial whether a better and much more homogeneous result might not be obtained

by abandoning altogether the use of "loam," or "dry sand," or any badly conducting moulds for bronze guns, and casting them in massive moulds formed of cast-iron, bored out internally to the exact figure of the gun, with a very small allowance for turning externally,—the iron mould being put together in pieces, separable not only horizontally into frusta, but vertically in a plane passing through the axis, so as to admit of the withdrawal of the gun when cast. Should the main object be found gained, of securing a perfectly homogeneous casting, without deterioration of the properties of the metal in any way that could not be met by suitable variation in its constituents, or in manipulation, then several important subsidiary ends would be gained also: such as greatly reduced cost and saving of time, and hence, increased production, by rendering needless the present system of loam moulding by skilled labour; absolute identity and perfection of form of the exterior of the gun when cast,—objects very ill attained, indeed, under the present methods, even in the best hands; great economy in the subsequent processes of finishing the gun, so far as turning its exterior is concerned; considerable economy in the amount of waste metal now cut off in turning.

Besides this, the casting in iron moulds would admit of an almost unlimited increase of statical pressure upon the head of metal, would facilitate the delicate process of casting bronze guns hollow, upon slender "loam cores;" would admit of the fluid metal being introduced into the mould at the bottom instead of at the top, with an ease and safety impossible with "loam moulds;" and lastly, would allow of the whole vertical mould and fluid metal within it being given a rapid motion of rotation round the axis of the gun during the process of cooling (if deemed desirable), by which a complete mixture and homogeneity of the included metal might be secured during the short interval that would elapse between the mould being full and the consolidation of the metal. The experience of brass-founders, in connexion with civil works, of late years, has largely extended the use of iron moulds, and shown their extreme utility and economy; they do not wear out or burn away, and once properly made and prepared, stand an almost indefinite number of castings.

It may be said, however, that if it be also a fact that small portions of oxygen, or other gases, are evolved from gun-metal at the moment of consolidation, such rapid cooling would result in the entanglement of the air vesicles so produced in the mass of the metal, rendering it porous and undurable.

It does not follow that rapid cooling would preclude the escape of such vesicles, if evolved, especially if powerfully aided, as they would be, by centrifugal force, bringing *them* to the centre and portion of the casting longest fluid, if the whole mould revolved upon its axis, as proposed: in the case of a gun cast solid, depositing such air-vesicles as had not time to escape, in the portion to be bored out; and in the case of one cast on a core, bringing them to the internal surface of the metal in contact therewith, where a ready escape would be found by them. This method of casting would also give great facility to cooling the gun by currents of air through the interior of the core, if found desirable, and admit again of any required slowness of final cooling after consolidation, should such be found to add to tenacity, &c. The author has learned that casting bronze guns in iron flasks, lined with thin coatings of clay, was proposed to the American Ordnance Department; he is not aware if it was ever tried, or with what results. That proposition, however, is essentially different from the one now made, as the author believes, for the first time, of absolute "chill casting" in naked and massive iron moulds, and with the additions proposed.

179. Many experiments have been made by Dussausoy and others, to improve gun-metal by the addition of some other third metal in small proportions. Iron, zinc, lead, antimony, &c., have been tried, in all cases with disadvantageous results. There are metals of one class, however, which have never been tried, and whose addition in minute quantity to gun-metal in the melting furnace would most probably prove a brilliant exception to those failures—namely, the metallic bases of either of the alkalies, potassium or sodium, preferring the latter as most manageable, to be had, even now in commerce, at a moderate price, and capable of being manufactured, were there a demand for it, at a price per ton not much exceeding common zinc. In the author's Third Report on Iron (Trans. Brit. Assoc. for 1843), he has given, some then, new, and remarkable facts, as to the action of sodium, in inducing the alloy, of metals having little affinity, in rendering more perfect and stable the union of all alloys, apparently by rendering the $\epsilon -$ and $\epsilon +$ metals still more electro-negative and positive; and lastly, in promoting union in metallic alloys, by instantly removing, all traces of suspended or combined oxides from them on its addition, the alkaline metal added, being at once divided into a portion which is decomposed by and reduces the suspended oxide, and another which

alloys with the metallic mass. The addition, then, of a minute dose of sodium to gun-metal while in the melting furnace and in fusion, the sodium being added in the state of alloy with a part of the tin, previously made, would afford the means of clearing the whole mass of metal instantly, from suspended oxides, and reduce it to absolute purity in every case, and in that of the re-melting of old guns would overcome all the difficulties experienced by the increased mixture of oxides due to the repeated meltings. Less than 0·05 per cent. in old, and in newly-made gun-metal perhaps less than one-quarter of that per-centage by weight, would be sufficient.

180. Nor are facts wanting to suggest the likelihood, that this addition, would positively improve the physical properties of the gun-metal. Thus Berthier ("Essais par la Voie Seche") records, having had presented to him a Swiss copper, remarkable for its extreme softness, malleability, and ductility. Upon analysis it proved to be an alloy consisting of,

Copper, ...	99·12
Potassium, ...	0·38
Calcium, ...	0·33
Iron, ...	0·17
	100·00

Berthier justly concludes that these peculiar and valuable properties of the alloy are due to the presence of the metallic bases of the alkali and of the lime, and suggests the value of producing such an alloy generally, in the fusion of copper by the simple means of using a flux of potash and charcoal. If, then, such effects result from the alloy of under 0·7 per cent. (taking the calcium and potassium together) of alkaline metals, in a copper containing as much iron as would *alone*, certainly make it harsh and brittle, it may be with some confidence anticipated that a like, or possibly a better, result would follow in the case of gun-metal. Berthier's proposed method of indirectly forming the alloy is not advisable, as not giving sufficient command, that the alkaline metal shall not be combined in excess, nor does the inducement of cheapness longer apply. It is probable that the gun-metal, to be of equal hardness as now, when thus alloyed, would require rather a larger proportion of tin.

May it not be that the well-known superiority and endurance of old Spanish cast guns is due not merely to their exclusive use of new metals for every casting, but to the existence of a minute proportion in the alloy of the alkaline metal, potassium, arising from the Spanish copper being smelted with wood fuel, and the foundry meltings performed with the same? Bell-founders are of opinion that wood fuel improves their metals, though its use is abandoned in England, from motives of economy, in favour of coal, with which all our copper is smelted. The well-known and most remarkable ductility, softness, and fluidity in fusion of Spanish pig-lead is probably due to the same cause.

181. The experience of ages has made the casting of bronze guns a matter almost of routine; but the results, as might be expected from the many conditions of difficulty thus briefly treated of, are still often uncertain or unmanageable. Some old Spanish guns, of large caliber (and the latter are less durable, than smaller guns) are stated on good authority to have withstood more than six thousand rounds, yet it is not unknown for several guns to be cast at the same "pouring," from the same furnace, and in the same sandpit, yet some of these guns shall stand 1500 or 2000 rounds, and others burst or otherwise give way, at or under one-tenth of the number. Though offering, therefore, facilities in boring and turning, and the advantage of being little chemically acted on by the corroding and deflagrating action of the powder (so that its effect, only becomes visible after perhaps 3000 rounds), or by the all-pervading chemical influence of air and moisture, gun-metal would be well replaced with the cheaper and more resistant wrought-iron, whenever means shall be obtained for working the latter into the required forms with facility, and certainty of result. For many years past field guns of *cast*-iron have been in satisfactory use by the Governments of Sweden and Denmark, and, it is said, of America. (Note O.)

182. It was stated in foreign journals, in 1846, that Baron Hackewitz, at Berlin, had perfected the means of forming bronze guns, by precipitation of the alloying metals together in suitable moulds by the galvano-plastic process;—that the method had been found eminently successful, in escaping (by this, as it were, humid gun-founding) all the difficulties of segregation of the metals and want of homogeneity incidental to the ordinary methods by fusion;—that a commission, at the head of which was Humboldt, had been appointed by the Prussian Ministry of War, to examine and report upon it, and that that Govern-

ment had at length purchased the invention for 36,000 thalers. No more has been heard in this country of the method, which has, therefore, probably not turned out as valuable as at first supposed. Were it not that the adaptation of wrought-iron to artillery forms our present horizon of improvement, rather than the improved use of bronze, it would seem a research worthy of careful experiment upon the large scale, how far this process might be advantageous. The means of thus precipitating together, in determinate proportions, two or more different metals, and the fact that when precipitated they form true alloys, has been known several years, and the conditions investigated by Becquerel and others. That metals so aggregated in some instances possess great solidity and density is certain, it being long well known to copperplate engravers, that the copper precipitated locally upon a rolled plate for engraving, is much harder and denser than the other parts of the plate, which were obtained by fusion, lamination, &c. Metals thus precipitated are, however, always aggregated in crystals, which, in accordance with the general law, will have their principal axes in the direction of least pressure while forming, which will probably be in directions transverse to the electric current. The molecular arrangement of the mass will, therefore, be very uniform and simple, and probably very analogous to that of cast-iron in cast objects; but the mutual coherence of the crystals, in the absence of all mechanical pressure upon the mass, may yet be very slight; homogeneity of composition, however, would be almost certainly attained.

183. Amongst the many projects for improved guns recently brought forward, there has been more than one for lining the interior of cast or of wrought-iron guns with gun-metal,—in fact, making a bronze gun, strengthened with iron externally. The idea is a very old one (see Note A), but practically valueless. No rigid combination of gun-metal and iron can be adopted with permanent success for artillery, from the great disparity of expansibility by heat, and of extensibility by equal strain, between the two metals,—the amount and some effects of which have been already discussed, and which in this case is sufficient to tear asunder ere long any connexion attempted between the metals.

184. In the comparative experiments made at Lafere with cast-iron guns made in Sweden, Scotland, and France, in 1836, there was good ground for believing that an appreciable weakening occurred, of the guns into which copper

cylinders had been screwed, through which the vents were bored, as compared with guns in which the vents were bored directly out of the solid cast-iron, and the evil is attributed to the metal of the gun removed, in addition to that of the ordinary vent, to make way for the copper, and to the excess of the expansion of the copper above that of the cast-iron, which grips it all round, when both are heated by firing, and thus produces a strain upon the gun. It will, however, depend upon circumstances whether the gun shall yield to the copper, or the latter to the gun, to such an extent, as to make the tension of the gun inappreciable.

20.—*Molecular Constitution of Bronze, or Gun-Metal, in Cannon.*

185. Gun-metal of the finest quality, when freshly broken, presents a beautifully fine matted fracture, nearly uniform, and of an even gold colour, with a few fine specks of brilliant light, uniformly disseminated. These are the facets of larger crystals; examined with the microscope, the whole mass is found to consist of extremely minute crystals.

Though the mass is crystalline, however, it is highly ductile, and unless the fracture be produced by a direct tensile strain, applied suddenly as an impact, the forms of the crystals are distorted and bent in its production, and the character of the fracture becomes changed and deceptive.

The size of the crystals is always very small, and their form unpronounced when the metal is good; but very minute changes in the proportions of copper and tin, combined probably with some conditions as to fusion, temperature, &c., as yet unascertained, occasionally give rise to a large development and singular regularity of crystalline structure.

This, however, is never developed to the extent frequently observed in the alloys of copper and zinc, some of which, chiefly those between ($2\ Cu + Zn$) and ($Cu + 2\ Zn$), Table x., may, by peculiar treatment, be obtained in crystals, as large or larger than those, found even in the hardest crystalline cast-iron (Speigeleisen). In such cases the principal axes of the crystals are found arranged according to the general law, in the lines of least pressure within the mass, on its consolidation.

186. From the minute size of the crystals of gun-metal, and possibly

also from their form, as yet imperfectly determined, it is scarcely possible to observe visually, any determinate arrangement of the crystalline axes, in good gun-metal, with reference to the contour of the mass; but some experiments which have been made abroad as to the relative tenacity of bars of gun-metal, cut from the same gun, in two different directions, and broken by transverse strains, appear to indicate distinctly that the molecular or crystalline arrangement of gun-metal in cannon develops itself in precisely the same manner as that of cast-iron in guns, or generally of all crystalline fusible bodies. Thus, when bars of equal section were cut from the gun, in a direction parallel with the axis of the piece, and others in directions radial to the axis, or perpendicular to the former, and both broken; the tenacity of the latter exceeded that of the former in about the ratio of 30 : 25. If the principal axes of the crystals be in the lines of least pressure, they must be found arranged radially to the axis of the gun; the maximum cohesive resistance of all metals is in the direction of the principal axes of the crystals (as, for example, in the line of the fibre or acicular crystals of rolled wrought-iron); but in this case we find the greater cohesive resistance is in the direction radial to the axis of the gun; we may, therefore, conclude, as the structure is crystalline, that the principal axes are in the same direction.

187. Gun-metal, therefore, comes within our general law as to its molecular constitution, but in proportion as the quality of the metal is bad, its substance *boursoufflé*, and filled with microscopic vesicles of gases liberated in casting or cooling, and rendered ununiform by the segregation of anomalous alloys, &c., in the same proportion will it be difficult or impossible to observe any normal arrangement whatever of its particles.

188. When bronze guns are burst in proof or service, or broken by the stroke of shot, a general and often strongly marked tendency to crystalline arrangement, radial to the axis of the piece, may be observed. We cannot, however, rest any decisive conclusions upon fractures so produced, inasmuch as the crystalline axes are changed, and often abnormally everted, by the action of internal compressions and extensions, beyond the elastic limits of the material, producing effects similar to those hereafter treated of as occurring in wrought-iron, at ordinary temperatures, when exposed to blows, or other violent strains or changes of external form, beyond the limits of recovery.

21.—*Steel as a material for Cannon, in relation to its Working Properties.*

189. In addition to what has preceded respecting the resisting powers of steel, both absolute and comparative, a few remarks are required as to its other properties in relation to our subject.

Cast-steel is that alone capable of becoming a material for ordnance, as the thin bars, alone capable of being obtained by cementation, are, owing to the difficulty of welding steel into larger masses, unfit for the large scantlings demanded. An apparent exception to this occurs in the *Stahleisen* of Styria and other parts of eastern Europe, which is obtained by a modified process of puddling, direct from the pig-iron, and hence at once in large masses. This steel was first brought prominently into notice for large constructions, by Herr Ignaz v. Mitis, who, in the year 1828, constructed a suspension bridge at Vienna of 334 feet span, the chains of which are formed of it. He states ("Beschreib v. die Carlsbrucke, der Ersten Stahls Kettenbrucke, in Wein:" 8vo, Wein, 1827) that this steel does not begin to stretch under 47,125 lbs. = 21 tons per square inch, and that he proved the chains of his bridge to 25 tons per inch of section.

This so-called steel, however, offers no inducement to attempt its use for guns; for, although low in price, obtainable in large masses without welding, and named steel correctly, in so far as it possesses the property of being "hardened" by sudden cooling, it is in fact, but a fine form of harsh strong iron, almost every example of which possesses more or less the same property of being thus hardened; for the finest steel passes by insensible gradations into the softest and most ductile wrought-iron, which receives little, if any, appreciable change in hardness from sudden cooling.

The resistance to tension of the Styrian steel is little more than double that of average wrought-iron, and its extension far less. Its coefficient T_r is, therefore, much below that of good soft wrought-iron.

190. Cast-steel, however, being in the course of its manufacture fused, although this is usually done in small and separate crucibles, is found capable, by dexterous management, of being cast into very large masses of nearly perfect solidity, which may be afterwards forged out under the tilt or steam-hammer into longer pieces of smaller diameter, with much facility, cast-steel being at a particular temperature extremely malleable. (Note P.) This is understood to be the

basis of Herr Kruppe's patent process, the steel, however, being primarily obtained by a regulated and skilful puddling, stopped at the proper moment, by which he has been enabled to form masses of unusual magnitude, and to manufacture articles of various sorts previously not attainable in steel, such as tyres for railway wheels, formed of one piece without welding. This steel presents no trace of fibre, its fracture seems the same in every direction, and its crystals are so minute that the lustrous surface of fracture on a large scale seems almost a vitreous one. As for size, he has pushed his manufacture to a point leaving nothing to desire, and it is capable of still greater extension. The price of the material, however, is high; and the subsequent cost of boring and turning necessarily very great.

191. In its softest state, fine cast-steel is so hard, that the *difference* in hardness, between it and the hardest steel tools designed to act upon it is so slight, as to involve the necessity of reducing the angle, at which the solid arris of all cutting tools meets the point of section, almost to zero—hence but little work done, in proportion to the labour expended, and rapid wear of the tool by abrasion, which constantly requires fresh grinding to edge. When, therefore, the cost of workmanship is added to that of material—the price of steel guns is, weight for weight, perhaps considerably more than that of gun-metal. There is also the possibility of cast-steel in guns getting in parts hardened accidentally, during the first steps of manufacture, which, if not discovered until after boring had partly been effected, might not admit of remedy. This property of steel, so valuable in most other cases, is a positive disadvantage to it as a material for guns, affording facilities for their total destruction by an enemy, or for their irreparable injury by the common accidents of conflagration and the usual means for its extinction.

192. One important element of material for an unexceptionable gun is, that its toughness should be such as to afford the fewest fragments, and no splinters, in case either of the gun bursting or being knocked to pieces by the stroke of shot; this is lost totally in cast-steel, which bursts into very numerous sharp-edged irregular fragments with many splinters, almost as a gun of glass might. From the extremely small coefficient of extension of cast-steel, the limit in thickness of a gun beyond which further increase of metal will be useless, will be sooner reached with this than with any other material for ordnance.

22.—*Molecular Constitution of Wrought-Iron, and the Law of Direction of its Crystals or Fibre.*

193. When wrought-iron in any of the usual forms of its manufacture is fractured, its molecular structure presents itself, more or less distinctly pronounced, in one or other of three forms:—

1°. Its mass consists of minute crystals of nearly uniform size, whose facets present themselves at all possible angles, like that of refined sugar.

This "saccharoid" structure usually belongs to the most highly refined iron, and often to hard steely irons, such as those of Sweden.

The larger bars of Low Moor iron present, perhaps, the finest examples of this structure.

2°. The surface of fracture consists of large, sometimes very large, lamellar spangles or plates, the facets of crystalline cleavage, whose directions tend to general coincidence with the surface of fracture. The number, size, and direction of these facets vary in the same mass with the direction of fracture. This is the structure of all large and heavy forgings, or very large rolled bars, in which the planes of crystallization tend towards a general perpendicularity to the surfaces of external contour. This and the former structure are often found irregularly united in the same surface of fracture in ill-manufactured iron, and, united with the succeeding, it is the usual one presented by small common bar-iron.

3°. The fracture (hard to produce, owing to the greater flexibility of the iron than in either of the preceding cases) when effected, presents long, parallel fibre, or bacillary crystals, running in the direction of the longest dimension of the bar. This is the structure of the best and toughest iron, such as that for making chains and rivets, good boiler-plates, &c. It is found partially combined with the 1st and 2nd in some inferior irons.

194. We found in cast-iron that the law of arrangement of its crystals is to place themselves perpendicularly to the surfaces of the mass. In wrought-iron

which is found chiefly in elongated masses, the tendency is upon the whole to place themselves parallel to the principal surfaces. It would seem, therefore, at first, that the law of aggregation, apparently so opposite, must depend upon totally different conditions; it is, however, essentially the same. *In wrought, as in cast-iron, the principal axes of the crystals, tend to assume the directions of least pressure throughout the mass, while exposed to pressure and heat, in progress of manufacture.*

195. Let us take the most strictly normal structure, the 3rd; for example a round bar of rivet-iron, half an inch in diameter. This has been formed by the pressure of the grooved rollers in directions transverse to the axis of the cylinder, pressing it smaller and smaller, and still elongating it from a short thick mass, whose original structure, if broken, may have been that of 1 or 2, the metal being constantly at a temperature at which it is as soft as lead. Heat is evolving the whole time, as in the case of cast-iron in cooling; but the pressures produced within the mass are of a different character, and arise from a different cause. In cast-iron they arose from the contractions of the mass in cooling: in the wrought-iron bar (relatively small in two of its dimensions, and, therefore, little affected at all, by contraction in cooling) the internal pressures are produced by the rollers: but their pressures are all in directions perpendicular to the length of the bar; or in our round bar in the directions of the radii of the cylinder. *The direction of least pressure is, therefore, coincident with the length of the bar, and this is the direction in which the principal axes of the crystals arrange themselves.* The same is the case with iron, drawn into wire, where the directions of maximum pressure being manifestly in the plane of the "draw-plate," the aperture in which, presses powerfully round the periphery of the solid passing through it, that of least pressure is, as before, parallel to the length of the wire; and so are the (fibres or) crystals arranged.

196. Heat, as increasing malleability and ductility, i. e., intermobility of particles, facilitates the arrangement; but as iron is a ductile substance even when cold, so heat is not essential to the molecular change in the arrangement of its particles; just as in cast-iron we saw that molecular transpositions may continue long after the mass has become solid.

197. This is as strictly in analogy with the observable facts of crystallization generally in other bodies (whether simple or compound, ductile or rigid, passing

through an intermediate plastic state, or crystallizing *per saltum*), which crystallize in bacillary or fasciculated crystals, as were the analogies we found in the case of cast-iron. Thus, for example, arragonite, tourmaline, gypsum, actinolite, manganese-alum (from Cape Coast Castle), amianthus, &c., &c., are all found frequently in embedded, more or less rounded fasciculi, of long, parallel, fibrous crystals. When these are examined carefully with a lens, the external crystals are always found more or less deformed by the pressure of the external embedding matrix, to which they are moulded, though not formed by infiltration and gradual filling of a mould. In every such case there are accompanying evidences of great pressure in directions perpendicular to the longest dimension of the bacillary mass. Thus nearly cylindric pencils of arragonite are found so formed in the intensely compressed chalk, overflowed by huge incumbent caps of basalt, in the north of Ireland. Similar pencils, though not cylindric, of tourmaline, are found in granite;—manganese-alum, and fibrous gypsum, in enormously deep beds of clays, which, when soft and plastic, transmitted the pressure of their own mass of hundreds of feet in depth, with the fidelity almost of a fluid;—amianthus in serpentines, whose configurations prove the former play of enormous pressures, through plastic masses since become solid and rigid; and the instances might be greatly multiplied (Note E).

Two of the examples given, arragonite and gypsum, present the remarkable identity that they are found both in the arrangement of the crystals of cast-iron, with their principal axes perpendicular to the bounding planes, and in that parallel to them, as now described, for wrought-iron; in each case the arrangement having followed the lines of least pressure, however produced, provided it were coincident in time with such other conditions, whether of ductility, plasticity, fusion, or liquidity by solution, as admitted of molecular transfer and re-arrangement.

198. Returning now to the wrought-iron rolled bar; while its diameter continues small or moderate, although in the progress of its cooling internal strains and variable pressures are induced by contraction, still, as almost any appreciable contraction is confined to the one direction, that of the bar's length, so these new internal pressures are inoperative in producing any distinct changes in the disposition given to the (fibre or) crystals in rolling. Not so, however, if the bar, in place of being of small diameter, be very thick in proportion to its length,

and its mass great in proportion to the pressure brought upon it by the rollers. The operation of rolling is then less effective in the first instance, to induce, by its pressure, a general and uniform parallel arrangement in length of the principal axes of the crystals; some remain in other directions to the bar's length, as they were developed in the previous heating or other process of manufacture. The bar, however, is now let to cool; fresh internal pressures now become developed by contractions within its mass; the cooling goes on much more slowly, for the mass is much greater in proportion to its surface than in the long slender bar, and hence there is time for the new play of forces to act in re-arranging the crystals. The heat is carried off most rapidly from the greatest surfaces of the solid, but these are the sides of the bar; the contraction is greatest in the direction of its length; the maximum pressure due to contraction, therefore, coincides with the length of the bar, and more or less of the crystals arrange themselves now *transverse* to the length of the bar, in the directions of least pressure.

199. Whether the crystals of iron expand and contract, by change of temperature, alike in all axes, is not known as yet; if not, and that the principal axes are those of greatest expansion and contraction, then, as the longitudinal contraction of the whole bar is proportionally greater than that in either of its other dimensions, so the previous longitudinal arrangement of the crystals, in so far as rolling has been operative in producing it, now increases the tendency to the secondary re-arrangement of the crystals, transverse to their former position. The small slender bar, which cooled almost instantly and at once, fixed the crystals in the longitudinal position they had assumed under the pressure of the rollers; length of time in cooling admits of the re-arrangement in the heavy thick bar, aided by the softened condition of the mass, as it passes gradually from a yellow heat to coldness.

200. Thus, then, as the mass, the relation of this to form, and hence to surface, and of all, to the pressure transmitted to the iron in rolling, and to those induced subsequently by contraction in cooling, are varied, so will the main directions of crystalline arrangement be in each particular instance, which may be either total and complete, as in the case of the slender bar, or partial and imperfect, as in the grosser bar.

201. But the evidences of *any* arrangement, also depend upon the extent to which the individual crystals in any particular "make" of wrought-iron are

susceptible of development in size. In the case of *very* highly refined iron (in the language of the iron-master, "over-wrought" iron, in which there has been no "cinder" left), with all its carbon perfectly combined, and thus approaching to steel, the crystals are so minute, often so perfectly microscopic, that in large bars no other than the uniform "saccharoid" structure is discernible, though the "fibrous" becomes perfectly developed in very small ones. This is the case with the fine Low Moor iron, which, in rolled bars of $2\frac{1}{2}$ inches in diameter and upwards, presents a fracture almost identical with that of cast-steel, but in rivet rods, a fine fibrous one.

202. I have used the term "fibre" as being already long in use, and conveying well the character of this particular form of crystallization to the eye; but it should be clearly understood that the "fibre" of the toughest and best iron is nothing more than the *crystalline arrangement* of inorganic matter, and that the false analogies continually used, in which such fibre is spoken of and reasoned upon, as if identical with that of organic bodies, such as wood, hemp, &c., have no reality or basis in nature, and only tend to mislead (Note E).

The principles upon which the development in size of individual crystal depends, however, will be best understood when we have considered the—

23.—*Effects on Wrought-Iron of Forging into great Masses.*

203. In rolled bars, which we have hitherto treated of, the pressure of the rolls unaccompanied by impact, though conveyed only to the one point of the bar at a time, is in succession, and with great uniformity, applied to every part of its length. Moreover, the intensity of the pressure upon the unit of surface, or in relation to the section of the bar, steadily increases as the latter diminishes in size or cross section at each successive passage through the rolls.

204. A very different set of conditions occur, however, in a forged bar or mass. The whole of the pressures now are due to impacts, suddenly applied to local points of the surface, and thence unequally transmitted through the ductile, or partially ductile heated metal to its interior. The pressure at the surface, due to any blow measured for the time of the hammer's descent through the space through which the surface before the blow has descended, is rapidly lost in transmission within the mass, by inertia, and by the corpuscular forces of whatever sort that the substance of the heated iron opposes to change of form. Blow follows blow

in continually changing directions, and on various portions of the mass; the directions of maximum pressure within it, as constantly change, as do the intensities of these pressures, not only in depth, but as transferred from point to point struck. The elasticity of the metal (though, no doubt, of a different sort, from its elasticity of rigidity when cold) still exists, but in different parts of the mass, is kept during the hammering, and perhaps for long after, in a state of variable instability.

The lines of least pressure, therefore, are constantly changing under all these varying causes, and with them the directions of the principal axes of the crystals, become changed and changed again, perturbed, broken, and confused ; and if the mass be sufficiently large when cold, and its forging completed, its fracture, however fine and good the wrought-iron, presents nothing but a confused mass of small crystalline facets, differing scarcely at all, except in brightness, from the appearance of that of bright-gray cast-iron, in moderately large castings.

205. Yet no change, other than that of molecular arrangement, has necessarily occurred in the large mass, for it is a fact, that such a confusedly crystallized mass may be built and "faggotted up" from small rolled bars, each of which is previously perfectly and uniformly fibrous; that they lose their fibrous structure, and assume the confusedly crystalline one in the process of being united by forging into one large mass, and that a portion broken or cut off from the mass may be again rolled down into small bars, which shall be as fibrous in structure as at first.

206. The difference of ultimate tenacity, however, due to this mere charge of molecular arrangement, is formidable. If the original bars of the "faggot" have a tenacity represented by 46, that of an equal section cut from the "faggot" will be only 38 ; and it will mount again up to 52 in the small bars rolled or forged down out of the faggot. Such were the results of actual experiments in America (Note Q).

207. The development in size of crystal varies with the particular sort of iron: it appears to be largest and most lamellar (in large masses) in the most highly refined iron, and which contains an unusual dose of silicium; but the relations of size of crystal to chemical constitution require much further examination. Wöhler, in a most interesting paper, "Sur la Crystallization du Fer" (Ann. de them. t. li. p. 206), describes cubic crystals with perfect faces as large as an

n ch on the side, which he was able to detach from the interior of a bar of wrought-iron which had long been at a white heat in an iron-smelting furnace, and which were cleavable into smaller cubes and rectangular tables. They contained about 2½ per cent. of silicium.

208. With the same iron, and same volume of forging, however, the size of crystal appears to be developed larger in proportion to the time that the mass is maintained hot, and in process of forging. This time is necessarily greater, as the mass is so, and as the operations of reducing it to required form, are more complex or laborious. In fact, as in cast-iron we saw that the crystals were larger, the longer the mass required to cool,—so in wrought-iron, they are larger, the longer it is kept hot. And thus it happens that in very large and massive forgings, requiring often to be maintained, perhaps for weeks, at temperatures, varying from a welding heat down to dull redness, crystals are developed within the mass, of a size materially to diminish, in some places, the average cohesion of the iron, where their planes of cleavage produce partial "planes of weakness." The size of these crystals is occasionally surprising,—the broadest and flattest planes of cleavage frequently running in the directions in which surfaces of the integrant "slabs" or portions of iron, of which the mass has been formed, have been welded together. The author has observed crystals so posited, presenting flat planes, as large as the surface of a half-crown piece, in forgings under seven tons weight.

209. Foreign charcoal-made iron, such as the Swedish, does not offer any advantage for ordnance over the best manufactured British wrought-iron. On the contrary, Swedish iron, though strong and harsh, is most uneven and unequal in quality, both as to strength and extensibility,—the same bar often presenting various forms of fracture, at different points, or even united at every point, which indeed must be expected, from the rude and imperfect mode of refining adopted with it. The Low Moor iron, which, like the Bowling, is well known as one of the finest makes in Great Britain, has been stated by Dr. Schafhaeutl (Phil. Mag. vol. xvi.) to contain arsenic in appreciable quantity, indeed, nearly 1 per cent. I am not aware if this curious circumstance has been verified as a general fact by any other chemist. It is certainly unusual, and it would be interesting to ascertain if it have any necessary connexion with the remarkable ductility of the iron.

210. A very large quantity of wrought-iron is made in North America with charcoal and with anthracite,—a fuel almost as perfectly free from sulphur; but the following results of trials of ultimate strength, by the Commission of the Franklin Institute, do not indicate that superiority, which has been so boldly asserted in certain quarters in England, of foreign iron, "which has never been exposed to the deteriorating influence of sulphur," over British "makes."

Experiments on the Relative Strength of American and other Wrought-Iron.

Make.	Mean Breaking Weight per square inch. lbs.
Missouri bars, ...	47909
Slit rods for nails, ...	50000
Tennessee, ...	52099
Salisbury, Con.	58009
Center Co., Pa.	58400
Lancaster Co., Pa.	58661
English bar iron, ...	59105
Swedish bar, ...	58184
Russian bar, ...	76069, low steel, in fact.
Cast steel, ...	130681

These remarks, with those of sect. 66, are sufficient to show that we need not go out of England for wrought-iron for ordnance, any more than for cast-iron, if we only take the requisite measures to make the supply of suitable materials worth the iron-masters' attention.

24.—*Relation of Elasticity to the Crystalline Axis.*

211. Some experiments of Mr. Fairbairn's, on the relative ultimate resistance to rupture of boiler-plates, when strained in the direction of their fibre, i. e. in the direction in which they were rolled, and transversely to the same, have induced him to come to the conclusion that there is little, if any, difference.

If the iron of the plates be so very harsh, rigid, and of bad quality, as to have *no* (fibre) longitudinal crystalline arrangement, but approach nearly to that of a slab of cast-iron,—this may perhaps be nearly true, but in plates or bars of good quality it is certainly erroneous. The few experiments (twenty in all) upon which Mr. Fairbairn's conclusion rests, even will not warrant it, if *one* result contrary to all the others, and so exceptional as to suggest the probability

of an error, be abstracted from the average deduced from the remainder; and it seems wholly disproved by the experiments of Mr. Edwin Clarke (Britan. Bridge, vol. i. p. 377), and by those of Navier ("Applic. de la Mecanique," t. i. p. 30). The former gentleman, Mr. E. Clarke, whose experiments are by much the most important we possess, inasmuch as he alone has attended to the relative extension of the iron in either direction, found that bars cut longitudinally and transversely from the same plate of fine fibrous iron of excellent quality, were broken by strains per square inch of section of—

	Tons.		Tons.
In the direction of the fibre, . .	19·66	to	20·2
Across the fibre, ...	16·93	to	16·7

—and that *the ultimate extension of the plate in the line of the fibre was double as great as transverse to it.* The latter, from the mean of ten experiments, found the ultimate strength in the line of the lamination and fibre, to that transverse to the same, in the ratio of 40·8 : 36·4 ; the iron being of a stiffness, that it began to extend sensibly under from $\frac{1}{2}$ to $\frac{2}{3}$ the strain of rupture.

The explanation offered by Mr. Fairbairn, that the difference may be owing to better modes of "piling the rough bars," i. e., crossing them, before rolling, cannot affect the question. The principles here enunciated, upon which the final direction of the fibre depends, as well as the facts known to every iron-master who rolls boiler-plate, assure us, that no matter how the rough bars are crossed or piled, the fibre of the rolled plate, if of well-manufactured iron, is uniformly in the direction of lamination. And, were it otherwise, Mr. Fairbairn's experiments would be wholly inconclusive, as having been made on iron, *confessedly not* having a distinctly longitudinal fibre, and, therefore, unfit for the proposed inquiry.

212. Taking the means of Mr. E. Clarke's experiments, then, at 20 tons longitudinal, and 17 tons transverse, the value of the coefficient T_r in each case will be—

In the line of fibre, = 234·84
Across the fibre, = 30·47

—taking the total extension = ·0016 in the first, and half that in the second.

We find, therefore, that *the elastic range of wrought-iron, of any given quality,*

depends upon the direction of the crystalline axes in relation to the strain, and that the elasticity is a maximum, in the direction of the principal axis of the crystals, or line of fibre; and the important deduction arises, that for artillery purposes, the ultimate strength of a gun, in which the explosive strains are all resisted by wrought-iron acting in the line of fibre, is to that of one acting transversely to the same, as 234·80 *to* 30·47, *or about* $7\frac{1}{3}$ *to* 1. This ratio expresses, in fact, the relative strength of a "twist barrel," and of a common "skelp welded" or longitudinally welded one; and more than the whole advantage of this difference is sacrificed and lost in massive forgings.

25.—*Effects of Forging into large Masses, on the useful qualities of Wrought-Iron.*

213. We have found that the effect of large increase in the mass, of wrought-iron, in connexion with its necessary or existing modes of manufacture, is to prevent by the process any regular or uniform arrangement of its integral crystals;—that as such masses are necessarily continued long heated while forging, occupy long in cooling, and contract considerably in all their dimensions in cooling, so the crystals are developed to a large size, and become arranged, to a greater or less extent, in directions transverse to the surfaces of external contour of the mass.

The results are irregular "planes of weakness;" reduction of ultimate strength, to resist a quietly and steadily applied tensile force of from 20 to 17, or in very large masses of from 5 to 4 in round numbers, and reduction of resisting power to such impulsive forces as are concerned with artillery, in the ratio of from $7\frac{1}{3}$ to 1, or probably even more; for a train of difficulties are introduced in the manufacture, and of injuries done to the chemical qualities of the material, in proportion as we continue to increase the magnitude of the mass to be forged.

214. When the mass exceeds a very moderate bulk (in breadth and thickness), the processes of rolling, &c., are at an end,—those of forging by the tilt or steam-hammer alone are available. Skilled labour, and all the mishaps to which the results of the most adroit workmanship are exposed, in dealing with the heating and hammering of vast and scarce manageable masses, are inevitable. The mass must be gradually built up and aggrandized in size, by continual welding on to it, of small pieces, involving reiterated heating and partial cooling; expo-

sure for weeks, perhaps, to a temperature at which the exterior of the mass gets changed more or less in chemical constitution, and at each welding the risk of inclusion of more or less slag, cinder, or other foreign matter. (Note R.)

At every additional piece thus laid on by welding, an additional doubt is produced, as to whether or not the weld be sound throughout,—no examination at the time can with certainty decide this. The mass, however, grows continually in bulk and weight; the inertia of the hammer (large and powerful as this has become through the intervention of the direct action of steam) becomes reduced in relation to that of the mass in the same ratio; the blow no longer acts with uniformity upon the mass submitted to it, but is nearly confined in effect to the immediate point struck. The mass, if very large, and especially if also long, cannot be all maintained hot, between the portions at a welding heat and those nearly cold, there are others at every temperature, and a large proportion at a "low dull red," a heat at which all wrought-iron is more or less crumbly and brittle. The jar and shattering vibration of every blow, as it thunders down upon the huge piece, is transferred to the crystalline particles of these colder or quite cold portions, and probably produces at length some considerable alteration of molecular arrangement, in deterioration of strength, and often, before completion, actually shakes the mass in two, at some point or other.

215. At length the limit is found, when, with our present known modes of working wrought-iron (even with the heaviest and best appliances), we can no longer add to its size. The limit is reached, by the failure of power to heat the mass, or the required part of it, to the welding heat. The time required for the piece to remain in the furnace to effect this, continually increases as its bulk grows, and with it, the sources through which heat is lost and dissipated; but a certain proportion of iron is burned away, or melted off from the surface at the part requiring to be brought to welding heat, and from the adjacent portions at every moment that it remains in the furnace, at last, as much in weight is burned off, and lost at each welding, as equals the weight of the "slab" or mass laid on, and the labour is then in vain; the work, like that of the embroidery of Penelope, becomes an endless task, and the limit has been reached, beyond which the piece can be forged no bigger.

The point at which this limit is reached, can be stretched a good deal by the extreme skill of the operative forgeman, and the skilful construction of his

furnace; but, however great these may be, the limit is at length reached by all; and with our existing tools in Great Britain is probably reached in every case, at a diameter (of a cylindrical mass) of about 4 feet, and about 20 feet in length.

216. To the unpractised, though perhaps scientific observer, who looks at one of those ponderous masses withdrawn from the furnace, glowing like a sun, and observes the apparently little effect that the thundering blows dealt by the steam-hammer produce upon it, it always seems, that nothing more is demanded than great increase of weight and length of stroke, or increased power in the hammer. This, however, is a mistake: good forging, in heavy masses, depends not so much upon the force of the blow, as upon its exact direction, and its application at the precise moment when the welding metal is fit to receive it. The only effect of great increase in the power, and especially in the velocity of the blow, is to shatter and dislocate the internal or adjacent portions of the mass, which are at or about a low (cherry red) heat, at which temperature the best wrought-iron appears to lose much of its plasticity of heat, and be comparatively crumbly and brittle. In fact, with existing hammers of 5 tons weight, and 6 foot blow, this effect is very frequently actually produced.

217. On masses of very large diameter, the effect of the heavy blow of the steam-hammer is frequently to produce a singular form of internal hollowness and unsoundness, at or near the centre of the mass, where perfect soundness may have existed in an early stage of the forging. The shock of each blow received at the surface, and the reaction to which is the inertia of the more or less softened mass in an exact opposite direction, gradually condenses the iron towards the circumference, *by drawing it away from the centre,* where large cracks open with rough torn opposing surfaces, and form irregular cavities. Sudden changes of dimension, as when large projecting "collars" are forged down to a "shoulder," produce the like effect from like causes. The mass is generally unsound towards the centre within the larger part of the mass. The effect may be illustrated, and is of the same sort in fact, as though a barrel *nearly* full of bullets were slowly turned on its axis and heavily struck at successive points all round its exterior; the bullets, at each blow, would all tend to jerk towards the point struck, with energy proportioned to their nearness to the blow, and, if by any means kept in the positions respectively assumed after each blow,

would at length be found ranged round the interior circumference of the barrel, leaving an empty cavity in the middle, in the line of the axis.

218. If we are to seek for future great extensions of our power, of producing vast masses of malleable iron (for whatever purposes) that shall give greater assurance of internal soundness, and preserve in the large all the qualities of uniform and determinate disposition of fibre,—in a word, all the valuable qualities of the best wrought-iron, as now known in small bars,—it must be by some vast extensions or modifications of the rolling process, accompanied by such improvements in the furnaces and modes of heating, as shall enable the largest masses of prismatic forms, to be produced out of more slender rolled bars, laid or "faggoted," and heated together, and at one welding operation, rolled (or otherwise pressed in the same constant direction at successive points) into one gigantic bar which, for artillery, might be then twisted by suitable machinery, such as that patented by Melling. To the subsequent operations of bending, cutting, or shaping such prismatic masses, however, so as to fit them, on a large scale, for the many general purposes, to which forged pieces or "uses," as they are called, are now applied, narrow limits of practical disadvantage and difficulty can be foreseen; and as regards the fabrication of artillery, it scarcely admits of doubt, that the limit of useful size has been already far surpassed, and that it is to a skilful and judicious combination of parts, each formed of malleable iron of moderate and manageable dimensions, rather than to forging in one huge piece, that we should look for the production of guns of the largest class in this material. We shall return to the consideration of the best modes of attempting this hereafter.

26.—*Change of Crystalline Axis in Wrought-Iron, Cold.*

219. Much has been loosely written of late years, on the supposed "loss of fibre," and change to a confusedly crystalline structure, in wrought-iron, by the mere effects of long-continued jarring or vibration, or very slight bending to and fro at ordinary temperatures,—many affirming stoutly the fact, but without bringing forward any instance or experiment that amounts to proof, and others denying it, asserting in explanation, that in the instances adduced the "crystallized iron was never fibrous," and which very probably has been the fact in most of the cases adduced.

220. The subject is one requiring, for its being completely understood, a very cautious and difficult research, but one worthy of being at once made. The following conclusions from existing knowledge may, however, be provisionally offered as probably not far from correct:—

1°. There seems no reason to believe that any moderate extension or compression, and, therefore, no moderate flexures, however long continued or often repeated, produce any molecular change whatever in wrought-iron, provided that—

a. The range of extension or compression be *far within the elastic limits.*

b. That the velocity with which the extension or compression is made be not extremely great, i. e. not approaching to or beyond the "pulse period," due to the elasticity of the material (134).

2°. Nor any reason to suppose that jarring or vibration, unless accompanied by some permanent change of form in the mass, is capable of affecting any molecular change whatever, provided that the material shall have been previously in a state of molecular repose, i. e. free from internal strains, due to form, contraction in cooling, &c.

Nor is it probable that abrasion alone, such as the grinding away of the bearings of railway axles, or the scoring and rifling of the chase of a wrought-iron gun by the passage of the shot, produces any molecular change, but—

3°. It does appear certain from many well-observed phenomena, that instantaneous changes of molecular structure, and reversals or transposition of the crystalline axes, can be produced in wrought-iron at ordinary temperature, by the violent application of mechanical force, producing suddenly change of form at one or more points of the surface of the mass, provided the directions of the force and the extent of change of form, be such as to produce internal strains and inequalities of pressure, and that the extent of these latter is greater in any one direction than the resistances due to the elasticity and its range in the material.

221. It would be foreign to our immediate end to pursue this subject here at any great length, however interesting and important, and with one familiar instance we must dismiss it.

The well-known operation by which a blacksmith breaks, cold, over his anvil, a bar of the toughest iron that can be had, and whose fibre is all longitudinal, consists in "nicking" one or both opposite sides of the bar, at the required point of its length, to a *very small* depth with a chisel having an edge formed to a very obtuse angle, generally about 90°, and driven into the substance of the bar, by blows from a sledge with great velocity. When this is done, a bar of moderate size, so tough and fibrous that at every other place it is capable of being bent sharply double without fracture, may be broken across at the "nicked" place, often by bending over one's knee; always by a few light blows transversely on the anvil.

When the fracture is exposed, the iron is found at the "nick" to be short and crystalline; the crystals are on the whole arranged transversely to the bar's length. Their facets are largest and most transverse, just at the sinus of the angle of the nick, and either no sign of the longitudinal fibre constituting the structure of every other part of the bar is visible, or occasionally some portion of the section at the side or part most remote from the nick, or in the centre between both, is still visible.

Now what happens in this is rendered obvious by the following diagram (Plate VI.), in which Fig. 1 represents the side of such a bar at the nicked place, and the change of direction there of the crystalline axes. But, what internal forces have acted on them to produce this?

Looking at Fig. 2, it will be seen that the driving the edge of the wedge-shaped chisel into the substance of the bar has produced compressions, whose pressures are propagated in directions perpendicular to the faces of the wedge or of the nick that is the express copy of it. These pressures, in the directions co, co', are resisted, and finally equilibrated by the elastic compression of the longitudinal crystals in the directions of their principal axes, namely, fo, $f'o'$; and the resultants of these mutual pressures meet in the substance of the bar, in the directions or, $o'r'$, which are those of maximum internal strain; but in the space between these, cd, approaching the angle of the nick, and perpendicular to these resultants, are the lines of minimum pressure. Now these are the new

PLATE VI.

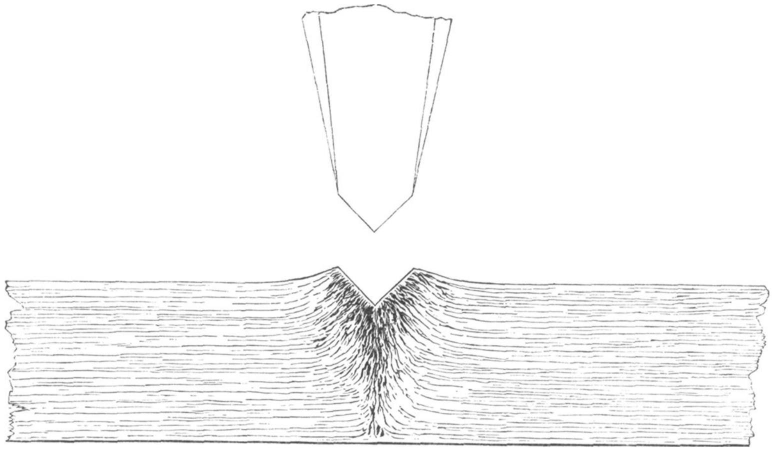


Fig. 1.

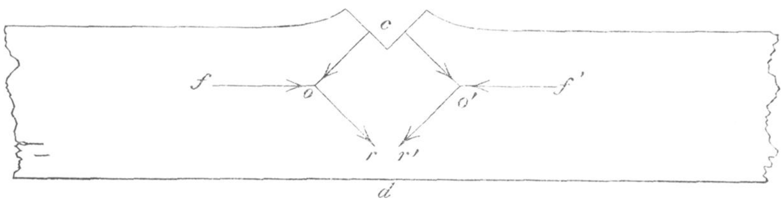


Fig. 2.

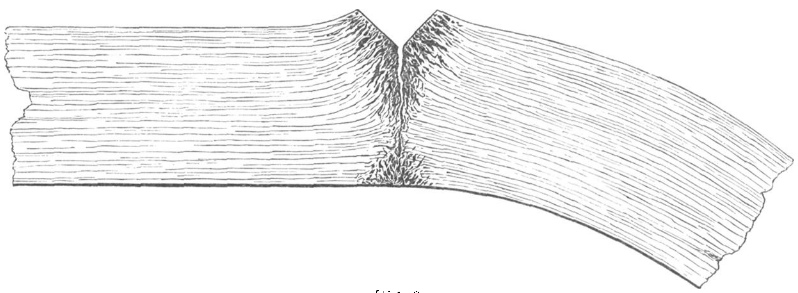


Fig. 3.

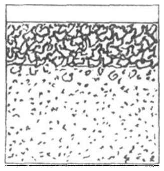


Fig. 4.

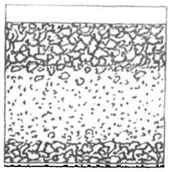


Fig. 5.

Change of Structure in Wrought-Iron, Cold.

directions that the principal axes of the crystals assume at the moment that these pressures disturb their previous equilibrium, that is to say, at the moment of making the nick.

Fig. 3 shows the further change in crystalline arrangement after that assumed by the bar, as above described, due to the "nick," and subsequently produced by the bending, prior to final fracture.

Supposing the bar bent by pressure, or blows, towards the side remote from the nick, as soon as the fracture is complete, it presents a surface, as in Fig. 5, consisting of facetted crystals, piercing the bar transversely from the angle of the nick to a certain depth; a central portion where the original longitudinal fibre of the bar has remained unchanged, but is broken across; and again, a narrow strip of flat facetted crystals transverse to the line of fibre, at the side furthest from the nick.

Now these latter, were produced by the bending of the bar, after the nick had produced the former. The side furthest from the nick is the *compressed* side of the bar, the neutral axis being somewhere between. *The direction of least pressure* at this compressed side is, therefore, *transverse to the bar*, and hence the new direction taken up by the crystals at this point, in accordance with the general law. Had the bar been bent towards the side nicked, in place of the opposite way, the nicked side, would have been the compressed side, where the transverse crystals were already formed, and the fracture, when broken across, would have been fibrous out to the very edge, remote from the nick (provided the whole bar had been uniformly fibrous beforehand, and nicked only at one side), as shown in Fig. 4; and for this reason the bar would have been harder to break in this direction, as every blacksmith knows to be the fact.

222. Thus, then, *this change of crystalline arrangement at ordinary temperatures is another case of obedience to our general crystalline law*, *that the principal axes are found in the directions of least pressure within the mass*, and that the change of direction is possible to be produced in "cold iron" is due to the fact, of its having more or less *ductility at all temperatures*, which means in fact that more or less permanent displacement of molecules is competent to the material at any temperature. There is, therefore, no ground for anticipating that wrought-iron artillery would rapidly or at all (if originally properly proportioned) deteriorate in tenacity, and so, gradually, and yet unascertainably, become unsafe in service.

223. A good deal of information on this subject occurs in Mr. Hood's Paper, on the "Changes of Internal Structure of Iron" (Pr. Ins. Civ. Eng., vol. ii. p. 180). He attributes the changes which he describes to the conjoint action of "percussion, heat, and magnetism," but without any distinct views or attempt at a united theory. He suggests no solution of the way, nor fixes any limits within which percussion acts; and the conjoint action of heat, and especially of "magnetism," appear perfectly gratuitous;—words without a physical idea.

224. Mr. Thorneycroft, also, in a paper on the same subject (Pr. Ins. Civ. Eng., vol. ix. p. 295), has collected some interesting facts, though his statements seem rather warped by certain preconceived views.

225. In no paper, however, that the author has seen, is any attempt made to connect all the phenomena of change of crystalline structure in iron at all temperatures, with the action of some one recognisable force, such as that which he believes to constitute the true solution and key to all the varied and complex facts noticeable, and which he considers he has been the first to enunciate, namely, *the arrangement of the principal axes of the crystals in the lines of minimum pressure within the mass.*

27.—*Effects of the Variable Rapidity of the Blow or of the Velocity of application of the Rupturing Strain, upon the character of Fracture of the same Wrought-Iron.*

226. It has been stated (section 113), that under the rapid stroke of cannon-shot, the longest and most fibrous wrought-iron breaks short and crystalline, like cast-iron.

About 1842, a number of experiments was made at Woolwich, under the direction of General Dundas, upon the effects of 32 lbs. shot, fired at short distances and at various velocities against wrought-iron targets variously prepared to represent sections of the sides of iron ships.

These experiments were generally understood at the time, to have been urged upon Government by certain promoters of iron ship-building, in the expectation that the results would signally establish the superiority of iron over timber as material for ships of war—a notion obviously founded on the tentative knowledge of merely practical men of the resistance of tough iron to a slowly acting detrusive force, such as that of a punching press, and not upon any just physical

conceptions. The results, however, of the experiments (at which the author was present), very rapidly dispelled all ignorance of the subject, and fully justified the conclusion, come to by Government, that plate-iron ships, as then (and still) constructed, are unsuited to the purposes of war whenever they may be exposed to shot. At low velocities, the laceration of the rivetted seams, and utter dislocation of the bolts connecting the opposite sides of the double-plated targets, was conclusive as to the fate of an iron ship (although prepared with 12 inches thick of India-rubber and cork lining), if exposed to a few rounds of large shot, fired at a very moderate velocity. In a scientific point of view, however, the most remarkable and important phenomena were elicited by the effects upon the plates of the shot fired with full service charges, and having a velocity probably not much under 2000 feet per second.

The effect on the plates, which were about half-inch thick, and of fine tough iron of the best quality, was to strike out an almost perfectly circular hole, a little larger in diameter than the shot, with scarcely any burr or bending of the edges, which were broken off sharp and square, and presented all round a large, well-defined, crystalline fracture, the planes or facets of the crystals very generally being disposed tangentially to the circumference, and perpendicularly to the plane of the plate. The piece struck out was shivered into fragments, seldom having a surface of above three or four square inches each, and all whose edges also were sharp, square, and crystalline, with the greater number of the planes of crystallization nearly parallel to the lines of fracture. The temperature of the pieces struck out and the iron around the aperture was raised, by the sudden rupture and change of form, from that of the atmosphere, to one so hot, that the fragments, when picked up at the butt, after having flown about 150 yards through the air, could not be handled with the naked hand, and in several cases the heat was sufficient to "blue" the surface of fresh metallic fracture.

227. Whence did this arise? Why should the velocity of the blow change the *nature* of the fracture of the broken body?—for there can be no doubt that any one of those plates broken by bending slowly backwards and forwards, or by striking over an anvil with the moderate velocity of a common sledge-hammer, would have been with great difficulty broken at all, and would at length have presented a long and irregularly fibrous or very partially crystalline fracture.

The fact has been long known to workers in iron, that no iron, however good and fibrous, will bear being bent double by the hammer, under blows exceeding a certain amount of velocity, known by tact and experience; and that by adroit management, in regulating the slowness with which the iron is so bended double, a very inferior fragile iron may be made to simulate, to an unpractised observer, all the external appearance, when bent, of the toughest; that, in fact, the rate at which iron can be bent double (cold, of course), is greater in proportion to its original toughness; but no explanation has ever been offered as to the cause; and as bad and fragile iron is always more or less confusedly crystalline in fracture, no observations were made as to any change in its character, dependent upon the rapidity of the strokes or other forces applied to bend it.

228. One part of the phenomena, however, viz., the relation between the toughness and the possible rapidity of bending without fracture, admitted of solution on well-known principles. If we gently apply the force of the hand transversely to a stick of cold sealing-wax, and continue the pressure long enough, we shall be able to bend it double. If we leave a lump of cold pitch, upon a flat plate, it slowly changes form and assumes that due to a viscous and imperfect fluid; but if we let the same stick of sealing-wax, drop from the hand upon a marble floor, or if we throw the lump of pitch against a wall, both are shattered into fragments, which alike break with a vitreous or resinous fracture. Nor is this confined to bodies possessing the great ductility and flexibility of pitch or shell-lac; for, going to the other extreme of rigidity, we find that even glass, proverbially brittle under the slightest shock, slowly yields and changes its form under a constantly applied force, so that the bulbs of very old thermometers, exposed for many years to the pressure of the atmosphere, less that of the included column of quicksilver, become diminished in capacity, as proved by the permanent elevation of the zero of the scale of those made by Sanctorio himself; or, again, that the marble slabs of our ancient mantel-pieces, exposed for years to the constant transverse strain of their own weight, and more expanded on their lower than on their upper sides by the radiating heat of the fire beneath them,—gradually sink down, and become permanently curved, the versed sine often reaching in this rigid material $\frac{1}{20}$ of the length.

229. In the case of slowly applied pressure the effect upon the material is

measured by the pressure P simply, and the limit of its equilibrium is established by the ultimate strength of the body only; but when the pressure is applied rapidly, or with velocity, its effect is measured by the square of the velocity, Pv^2, and equilibrium depends upon the range of elastic compressibility or extensibility of the body, and, as long since explained by Dr. Young, upon its modulus of force transmission; for if the velocity of impulsion, be to that of force transmission, in a greater ratio than the coefficient of final compression or extension at rupture, due to the material, bears to the length or depth of the body compressed or extended, destruction of continuity must occur, since the body is broken in successive infinitely thin *couches*, the time not being sufficient to admit of the transmission of the force from the first point of contact, beyond it to other or distant parts of the mass.

So that if μ be the modulus of force transmission (sect. 134), and ϕ that of final extension or compression at rupture, $\frac{\mu}{\phi} = V$, the velocity that shall insure fracture; and as $V^2 = 2gh$, the *vis viva* required for fracture is,

$$\left(\frac{\mu}{\phi}\right)^2 \times P. \tag{56}$$

230. Thus, for wrought-iron we may assume the modulus of force transmission at 13000 feet per second, and $\phi = 0{\cdot}05$, or $\frac{1}{25}$. From which we find, that the impulse of any perfectly rigid body, striking it with sufficient force, will produce fracture (and not bending, however tough and good the iron), if its velocity exceed 560 feet per second, or between one-third and one-fourth that of a cannon-shot. Where the striking body is itself compressible (as is always more or less the case), the velocity required will be rather greater, and the more so as the compressibility is greater. Hence, in the case of impulse produced by the mass of a *highly* compressible body, such as that of the elastic gas liberated suddenly from the explosion of gunpowder, the velocity of its motion requires to be enormous, in order *to produce fracture thus by its own impulse only*,—a consideration by which we arrive at a clear conception of the almost inconceivable velocity of development of the elastic matter from the explosion of fulminating silver, and other such compounds, which produce fracture upon

solids, in contact with them at the moment of explosion, almost with the facility of rigid solids. Thus, a few grains of fulminating silver strike a hole through a thick iron plate, or indent the face of a steel anvil on which they may be exploded. Indeed, pursuing this consideration, we might calculate the velocity of evolution of the gases of decomposition of such bodies, which has not yet been done. Except, therefore, under the stroke of such formidable compounds, we need never dread the fracture of any of the metals applied for ordnance, by the *velocity* of impulse from the mass of an elastic gas *only*. The striking mass requires to have the rigidity and weight of a solid body to produce fracture at lower velocities.

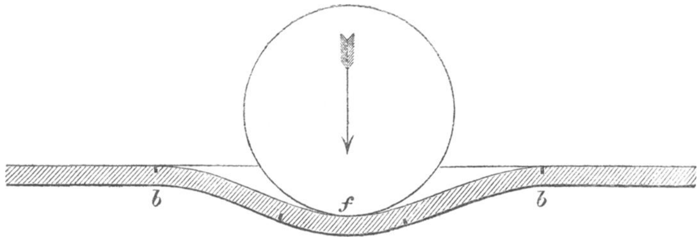
231. But in all these cases the character of the fracture is the same, whatever be the velocity with which it is produced. The sealing-wax and the pitch, alike, present a vitreous fracture, whether broken slowly, or shattered suddenly against a rigid mass. The glass and the marble present their characteristic fractures, whether broken by the most gradually applied push, or the sharpest blow ; and so also for every class of unorganized bodies we are acquainted with, except one, namely, that which embraces all bodies possessed of a certain amount of rigidity and ductility united, in connexion with a crystalline arrangement, or the power to assume it.

This class is chiefly confined to the metals, and amongst many of these we find that the character of the fracture varies with the velocity of the blow.

232. This alteration of fracture is due, then, to either of two causes, or to both conjointly sometimes, viz., either to condensation and hardening, produced by compression, or to crystallization, induced or altered at the moment by compression; and it is not improbable that every case of metallic hardening by flexure, or by compression, or change of form, is only one of inceptive or incomplete crystallization, for the metals that crystallize least perfectly and readily, and whose annealing temperature is extremely low (subsequent sections), such as lead and tin, are those that are scarcely hardened at all by flexure, compression, or change of form. Thus, it is scarcely possible to break a piece of pure lead by bending it backwards and forwards any number of times.

233. To limit ourselves, however, to the case of wrought-iron, the rigidity of which is readily and powerfully affected by compression and change of form. When a thick plate is struck by a shot, its plane surface, for the instant

preceding fracture, tends to be bent with curves of contrary flexure into a hollow, whose section is thus compressed at f, b, and b', and extended at the



other sides of the plate opposite to these letters. We say *tends* only to bend, because, on the principles already stated, time is not given it to bend; but the extensions and compressions occur in the plane of the plate, the same as if bending did take place by the directions in which the striking out of the fragments takes place in the way already described. Thus, then, we have pressures instantaneously propagated through the mass, radially from the point of impact of the shot, and in the plane of the plate, forming a circle of compression, at the struck side, whose centre is the first point of impact, and its boundary evanescent, and surrounded by an extended annulus, and the exact reverse of all this at the back or opposite side of the plate, the extensions and compressions being all radial to an axis passing through the plate at the point first struck.

234. The effects on the crystallization of the iron is precisely analogous to those described further on in breaking a bar. Lines of maximum and of minimum pressure are produced within the plate; its crystals, all probably lying originally parallel to the plane of its surfaces, and to that of its original lamination, are instantly changed in direction; their principal axes are reversed, and assume the directions of minimum pressures within the mass, which are those of tangents to the circumferences of the circles of extension and compression, and such are just the directions in which we find them. The iron, therefore, breaks short and brittle, because of the velocity of the blow, and the relation of this to its elasticity and elastic range (ϕ); and it would do this whether the character of the fracture were altered (as produced by breaking slowly) or not, but the alteration of the fracture from fibrous to crystalline is due to the sudden compressions and extensions visited upon the internal parts of the plate. It is, therefore, only another case of our general law of crystalline

arrangement; the principal axes assuming the directions of least pressure. As the planes of weakness in wrought-iron are the planes of cleavage of its original crystals (i. e. the crystals in its mass as manufactured), so when these are originally confused and partly transverse, the bending double a bar of such a character (i. e. of bad iron) becomes doubly difficult:—1st. Because of the original crystals transverse to its length; 2nd. Because of those induced in the process; the rate of bending, therefore, must be proportionably very slow.

235. The author is not aware that any explanation on just physical grounds has been before offered of these well-known phenomena. Swedenborg, in his large work, "Regnum Subterraneum sive Minerale, de Ferro," published in folio at Leipzig in 1734, Par. xxv. pp. 215, 267, 270, has described with much accuracy several of the forms of crystalline arrangement of wrought-iron, and of its passage into steel; and some interesting observations on the crystalline fracture of wrought-iron, by M. Aug. Malberg, will be found in the "Bul. du Musée de l'Ind. de Brux.," 1846; but neither these, nor any other author, appear ever to have grasped the leading thought, which is the key to the question. Upon these principles depends—

28.—*The relative Injury done by the Stroke of Shot, to Guns of different Materials.*

236. Experiments were made in France, at Lafere, in 1836–37, by firing round shot *en ricochet* at 100 metres range, at equal-sized guns of cast-iron and of gun-metal, which proved decisively in favour of the former as respected the resistance offered to injury thus caused; every diametric stroke of round shot, even with very reduced charges, producing dinges, or indentations, upon the bronze guns, reaching to the interior, to such an extent as to prevent the possibility of afterwards ramming home a shot. (Thierry, "Applic. du Fer, &c." 2nd partie, p. 125.)

237. It is believed, that no similar experiments have been made on any wrought-iron gun; but the point is one not difficult to predict accurately upon.

The stiffest (or most rigid and tough) and heavest material, is that which must suffer least by a given impulse from a harder body, provided that fracture do not result from the blow.

238. With steel guns, reduced in scantling at all in proportion to their assumed resisting powers, fracture would, in all probability, follow the stroke of shot; the latter being shattered, also, into a formidable "mitraille" against the gun. The chances of this are much less with cast-iron, and less again with wrought-iron. If the mass of the wrought-iron gun, remain not very much reduced below that of a cast-iron gun for equal caliber, there is no reason to suppose it would be more liable to injury than the cast-iron gun. But, if the relative mass of metal for the same caliber were seriously reduced, as might be done with wrought-iron field guns, of equal resisting powers with existing ones of bronze, more susceptibility to injury thus, might be anticipated; but still very much less than the amount to which the bronze field-guns of all the world (excepting the few cast-iron field-guns said to be employed in Sweden, Denmark, and the United States) are at present obnoxious.

29.—*The mutual relations of the Material of the Gun and of the rapidity of Explosion of the Charge.*

239. Since the year 1801, when Howard published his discovery of fulminating mercury (Phil. Trans.), and his experiments, with Keir, upon its effects when substituted for gunpowder in fire-arms, it has been recognised, that some explosive substances become gaseous with inconceivably greater rapidity than others; that, in fact, the word explosive merely expresses a vague relation between the volume of gas evolved from a solid or liquid, in changing its state by chemical or molecular action, and the time occupied in that change; so that the coal that slowly becomes water and carbonic acid, &c., in our domestic fires, and the gases suddenly liberated from an ignited charge of gunpowder, are but extremes of a line of similar phenomena, connected in character, and differing mainly in rapidity.

240. Yet the explosion of gunpowder itself, estimated by Hutton as expanding at a velocity of about 4700 feet per second, and found by Robins to be probably about 7000 feet per second, is a comparatively slow combustion, and conversion into gaseous matter, exceeded greatly in rapidity by many known agents,—amongst some of the best known of which may be named, in the relative order of rapidity of explosion :—

Chloride of nitrogen.
Iodide of nitrogen.
Fulminate of silver.
Fulminate of mercury.
Fulminates of several other metallic bases.
Pyroxyle, or gun-cotton.

241. Gunpowder itself also differs much in the rapidity of its explosion according to the density and mode of the charcoal having been burned, its state of aggregation, the fineness of levigation and intimate admixture of all its constituents, and their relative proportion, the size, form, and density of the grains, and highness of "glaze" of the powder, and its perfect dryness. When all, or the chief of these numerous conditions, are united favourably in certain gunpowders, their rapidity of explosion is so great, and their injury to fire-arms so remarkable, that they are known in France as "poudres brisantes." This property is still further exalted if the powder be slowly heated up to nearly the highest point it will bear without decomposition, prior to ignition (as when charged into a heated gun, in the way previously alluded to) (sec. 89). It is stated that a temperature of 160° Fahr. increases the effect of the explosion $\frac{1}{5}$, and that one of 400° nearly doubles it (Straith on Artillery, p. 554). This effect is not so much due to increased tension of the gases evolved by elevation of temperature, as to the state of unstable equilibrium into which the elements of the compound are brought by its gradual increase, towards the verge of that at which total subversion occurs, producing far greater rapidity in the explosion when it does occur.

242. A very simple and beautiful, though not very common experiment, well illustrates this. If a common Congreve or Lucifer match (those made of sulphuret of antimony and chlorate of potash answer best), be slowly and cautiously heated up for a minute or two, nearly to its igniting point, by being held close to a fire, or to a heated iron bar, and then ignited, it no longer catches fire and blazes, burning gradually out, as when lighted in its ordinary condition, but explodes suddenly, with a sharp loud report, and this, whether ignition be in this state produced by friction only, or by contact of an ignited body.

The effect of the gradual exaltation of temperature, in either case, is to

diminish still further the moment of time before required for the change, from the solid to the gaseous state. The distress upon the gun, however, is dependent upon the shortness of this time of explosion.

243. Neglecting the inertia of the charge itself, and supposing it fired from the centre, so that its evolved gases shall have equal density against the breech and the shot, if P and P' be the weights of the shot and of the gun, the total *vis viva* of the explosion is,

$$\frac{P}{g}V^2+\frac{P'}{g}V'^2, \tag{57}$$

and

$$\frac{P}{g}V^2=\frac{P'}{g}V'^2, \tag{58}$$

the *vis viva* of the shot, and of the recoil.

244. Assuming that the "work done" upon the shot, and upon the gun, is, in the case of every explosive agent, proportional to the volume of gases evolved, and that this is proportional to the weight of the charge, p, we have, for different velocities, and weights, of shot and charge, the proportions

$$PV^2 : P'V'^2 :: p : p'.$$

For, the same shot $P=P'$, with different charges,

$$V^2 : V'^2 :: p : p', \tag{59}$$

and for the same charge $p=p'$, with different shot,

$$PV^2=P'V'^2,$$

or,

$$V : V' :: \sqrt{(P')} : \sqrt{(P)}. \tag{60}$$

This law, first given by Hutton, as deduced from his experiments, has been subjected to fresh investigations by Colonel Mallet, of the French Artillery, by General Piobert, and others, and has been verified for gun-cotton as well as for gunpowder.

245. In the following Table the results of some of these experiments are given, in which the vast differences in effect, due to difference of aggregation, composition, &c., in the charge, are manifested :—

Table XII.

Explosive Agent.		*Vis Viva* of the shot. $\frac{P}{g}V^2 = np.$	Charges equivalent to equal ranges.
Gunpowder of Bouchet, .	Blasting powder, ...	28·37 × p	14.70 grm.
	For small arms, ...	52·50	8·00
	For cannon, ...	59·00	7·10
Gunpowder of Esquerdes, .	Fine sporting powder, . . .	72·83	5·77
	Finest glazed sporting powder,	82·14	4·55
Gun-cotton, .	Carded, of Montreul, . . .	159·25	2·83
	Carded, of Bouchet, ...	142·00	2·95
	Spun, of Bouchet, ...	147·60	2·85

In round numbers, therefore, 3 lbs. of gun-cotton will do the work of 8 lbs. of gunpowder; but its effects may be enormously more destructive upon the gun, though producing only equal effect upon the shot.

246. As stated at the commencement, the question of stress upon cannon, resolves itself into one of maximum pressure per square inch. The researches of Piobert have shown, that as a determinate time is necessary before the inertia and compressibility of the shot can admit of its sensible motion, so this maximum pressure (with all other conditions the same) is greatly increased, and the maximum more rapidly reached, from the first instant of ignition, in proportion as the powder is of a quality to burn more rapidly: so that, carried to its extreme limit, as in the firing of some of the fulminating compounds, the gun is burst before the shot is sensibly moved, and the velocity attained by the latter is very slight.

247. In order to determine, in an approximate way, the relative maximum mean pressures of the gases from gunpowder and from gun-cotton at different moments of the traject of the shot along the chase,—equivalent charges, viz., eight grammes of gunpowder, and three of gun-cotton, were fired successively with the same shot, from guns of various length, namely,

64, 49, 38, 29, 22, 16, 11, 7, 5, and 4

calibers in length, and the velocities of the shot, measured by the balistic pendulum,

$$\frac{\frac{1}{2}\frac{P}{g}V^2}{L}, \tag{61}$$

L being the length of the chase, or rather of that part of it passed through by the shot, is equal to the mean effort of the charge. This mean effort, and the pressure per square inch due to it, is always below the maximum mean effort, or pressure, and the latter is most in excess of the mean, where the length of the gun is greatest. Hence, comparisons of mean pressure for gunpowder and gun-cotton will be nearest the truth when taken for the shortest trajects within the gun, or at moments nearest to that of ignition.

The following Table gives the velocity, *vis viva*, and mean effort, due to gunpowder and gun-cotton, within the limits tried :—

TABLE XIII.

Lengths of Gun.			Velocities Given.		Vis Viva.		Mean Effort Produced.	
In Calibers.	Chase.	Traject in Chase of Shot.	Gunpowder.	Gun-cotton.	Gunpowder.	Gun-cotton.	Gunpowder.	Gun-cotton.
64	1·083	1·035	376·72	376·59	416·4	416·4	201·2	201·2
49	0·833	0·785	376·18	387·33	415·2	440·5	264·5	280·6
38	0·646	0·598	349·53	379·62	359·0	424·1	300·2	353·8
29	0·493	0·445	316·87	358·52	294·6	377·4	331·2	424·7
22	0·374	0·326	386·07	360·38	240·2	381·3	368·3	584·3
16	0·272	0·225	261·20	326·51	200·2	313·0	446·8	698·7
11	0·187	0·139	220·96	294·38	143·1	254·4	515·3	915·2
7	0·119	0·017	161·65	250·54	76·7	184·3	539·9	1297·9
5	0·085	0·037	115·27	175·94	39·0	90·8	526·9	1228·3
4	0·068	0·020	89·33	119·23	23·4	41·7	585·3	1043·5

The Dimensions are in Metres, the Weights in Kilogrammes.

248. It results from these experiments, that the velocity of the shot does not increase beyond 49 calibers; that at 64 calibers the velocities are equal for gunpowder and gun-cotton, and at greater length of chase the latter would begin to lose velocity; that the mean maximum effort of the gun-cotton, constantly increases, above that of the gunpowder, in proportion as the length of the chase

is reduced; and that the maximum tension is attained when the shot has been displaced 0·075 metres. It is, then, for the gun-cotton, = 493·4 atmospheres, while at the corresponding length for gunpowder it is only = 227·7 atmospheres.

It follows, then, that the strain upon the gun for equal ranges, and equal weight of shot, is with gun-cotton about double that with gunpowder.

249. Had we learned, experimentally, the actual time required for the ignition and complete combustion of given weights and volumes of gunpowder and of gun-cotton, more precise conclusions could be arrived at as to the best material for cannon intended to be fired with the latter. With the exception, however, of a single set of experiments made by the author, as to the time of explosion of some rather large charges of gunpowder, by means of the chronograph, incidental to his experiments on earthquake-wave transit (Trans. Brit. Assoc.), no experiments seem as yet to have been made on the subject.

250. With guns whose resistance to ultimate rupture shall be so proportioned by excessive scantling as to be far within the limits of safety, there can be no doubt that the metal whose period of force transmission is highest will suffer least from the rapid blow of gun-cotton, while the ductility of gun-metal must render it susceptible of rapid injury of local form by it; and should the extreme lightness of gun-cotton as ammunition for field artillery ever induce its general adoption for that arm (as the experiments in Bavaria and Austria seem to render somewhat probable), there can be no doubt that wrought-iron field-guns would be found the best fitted to resist its action, if properly made; their length being reduced and thickness varied, in accordance with the above experiments, and the external contour of the gun wholly altered from the established models of brass field-guns.

251. While, however, a metal comparatively rigid and highly elastic will suffer least distortion under the stroke of gun-cotton, or the like rapidly exploding agents, there may be ground to apprehend that internal molecular injury, and final dislocation, may more or less slowly result from the shattering jar of such explosions, and most of all so, in a loosely coherent and crystalline mass, such as cast-iron, although such might not occur with gunpowder, or be much more slowly produced.

252. That particular form of destruction upon long-continued firing which

appears to wait on heavy cast-iron guns, due (as already explained) to the local internal strains induced by the condensation of the metal at the interior of the chase, must with gun-cotton be greatly accelerated. On the other hand, the heat evolved is much less from gun-cotton than from gunpowder, and hence less powerful internal strains from unequal expansion of the gun.

30.—*Material of the Gun in relation to Chemical Action of the Charge.*

253. Sulphuret of potassium, converted in great part while in a nascent state instantly by oxidation into sulphate of potass, and water, appear to be the main agents, resulting from the decomposition by ignition of gunpowder, capable of acting destructively upon the gun. In the case of gun-cotton, nitric acid and water are the agents in a like predicament.

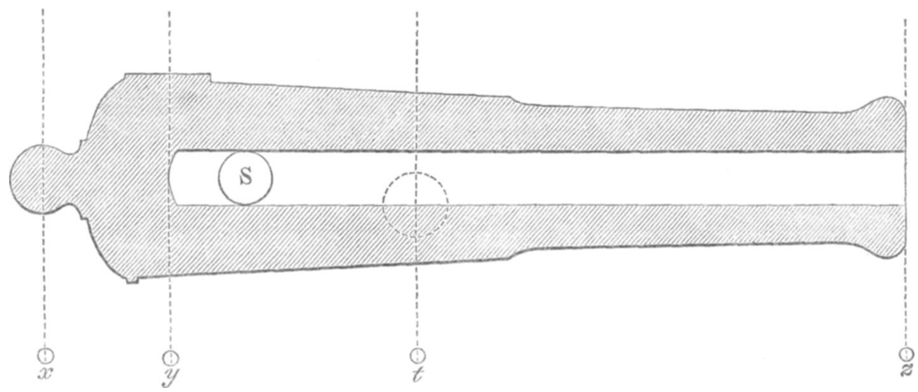
254. Water, combined with or acting along with air, as is always the case here, reacts with rapidity in corroding iron and cast-iron, the extent of which, for unit of surface and in relation to time of action, have been given very fully in the author's researches on the Corrosion of Iron (Trans. Brit. Assoc. 1840); but neither air nor water, nor both, have a very appreciable corroding action upon gun-metal.

255. Upon all three, cast-iron, wrought-iron, and gun-metal, the oxidized compounds of sulphur, as well as the alkaline sulphurets, act with rapidity, perhaps more destructively upon gun-metal than on either of the other metals, producing a form of local corrosion that eats the metal into pits and small cavities, not unusually found in the interior of old guns.

256. The most formidable chemical re-action, however, produced in any species of ordnance is that by which the vents, and portions of the interior of the chase near the seat of the shot, become so much enlarged in continued firing from cast-iron guns. This, which has been always attributed solely to gradual rending off and blowing away mechanically of minute successive fragments of the metal from the neighbourhood of the vent, by each discharge, is in fact a veritable deflagration of the uncombined graphite contained in the cast-iron, and of the metal itself. (See Note D.) The carbon first, the metal itself directly afterwards, burn just as the carbon of the powder itself does, and the remaining metal, rendered soft and porous where this occurs by the initiatory burning

out of the graphite, is rapidly swept away by the blast of each successive discharge. Copper vents, or, still better, red gun-metal (copper with about 3 per cent. of tin), bouched into the gun, appear to remedy this to a great extent. The French experiments at La Fere, however, gave some ground to suspect a weakening of the gun by the excess of expansion of the copper plug. It would seem that a far better method than "tapping" or screwing in the vent-plug might be adopted, giving the power of renewal, and of rendering the gun unserviceable or serviceable again in a few seconds, without the necessity of spiking and unspiking, and preventing the possibility of the latter being effectually performed.

31.—*Of the Position of the Trunnions upon the Strength of the Gun.*



257. The mass of the shot, whose diameter is D, being M, and its initial velocity v, and the mass of the gun M', neglecting that of the powder, the *vis viva* of its explosion is (Eq. 58)

$$Mv^2 + M'v'^2,$$

and that of the recoil $M'v'^2$. The latter, transferred as a pressure against the interior of the breech, is propagated as a force tending to stretch the metal of the gun from the section y in line of the axis towards the muzzle z; the rate of propagation, being (Eq. sect. 134) extremely rapid;—most so in steel; least so in gun-metal; in either so rapid that, to the senses, the whole gun recoils together and as one mass, and at the same instant; yet in reality the first effect of the recoil is to elongate the gun, pushing out the breech part like one

end of a spiral spring; the elongation traversing the whole length of the gun, and arriving at the muzzle, leaves it at its original length, assuming the elongation to have been far within the elastic limits. In its rapid progress, however, it has produced a strain in succession in the line of the axis upon every part of the gun.

258. If the gun have no trunnions, but, resting without friction, abut firmly against a fixed obstacle against the breech at x, then the segment in rear of the cartridge will be compressed by a force equal to the whole recoil in the direction yx, while the remaining parts of the gun will be extended by a force in the direction yz, which, at the transverse section y, is equal to the recoil, and at the muzzle is $= 0$. If F, then, be the work done to tear the gun in two at the section y, and $t =$ the momentary time of the traject of the shot along the chase until leaving the muzzle,

$$\frac{M'v'^2}{2}t = Ft \tag{62}$$

will be the longitudinal strain upon the gun.

259. If the breech be unsupported at x, the strain tending to tear it off at the section y is $= \frac{M'v'^2}{2}t$, diminished only by the inertia due to its small mass between y and x, or,

$$Ft = \left(\frac{M'v'^2}{2} - \frac{mv'^2}{2}\right)t. \tag{63}$$

260. If the gun be fixed rigidly on trunnions placed in the usual position at t, the strain tending to tear or break them off is equal to the whole work done by the recoil. The bearings always yield something, however.

The tendency to tear the gun in two at the trunnions, if M'' be the mass between x and t, is

$$\left(\frac{M'v'^2}{2} - \frac{M''v'^2}{2}\right)t. \tag{64}$$

This extension in the section at t at the first moment is, on the principle already stated, followed by a compression in the direction zt, of equal amount, and so for any other position of the trunnions.

261. The amount of extension or compression, assuming the gun of equal

transverse section of metal throughout its length, and its elasticity perfect, being given by equations 19–27, it follows that the longitudinal strain upon the metal of the gun, due to recoil, will be a minimum, if the trunnions be placed at the farthest point to the rear (as in mortars); or moves completely, if there be no trunnions, and the gun be firmly and rigidly supported against the recoil at the breech.

262. But in every case there is a certain amount of end-on strain; the metal of a gun is, therefore, at the moment succeeding explosion, subjected simultaneously to three different strains, acting at right angles to each other—the tangential or bursting, which is extensional, and accompanied by compressive or radial strains, which are normal, and the longitudinal re-active strains of the recoil, chiefly extensional, in line of the axis. There are good grounds for presuming that the existence of the two latter tend to a certain extent to weaken the resistance of the metal to the former.

263. The author is not aware that any direct experiments have as yet been made with a view to ascertain what effect would be produced upon the tenacity of a prism or bar already strained in the direction of its length by the application of new forces of extension or of compression along its whole or part of its length, and perpendicular to the former. Whatever hypothesis be made as to the law of aggregation, or of lateral adhesion of the ultimate molecules, it would seem to follow inevitably, that lateral extending forces must reduce the tenacity of the bar, and *probably* that lateral compressive forces might increase it, dependent much, however, as regards the latter case, upon the relation between the ductility and the ultimate cohesion of the material. If we assume the molecules arranged equidistantly in parallel equidistant lines throughout the bar (like strings of beads), whether opposite each other in the same transverse section, or (quincunx) each falling into the space betwixt two of the adjacent ones, and attracted mutually by a force varying by whatever law with respect to distance, it would seem likely that a force acting transversely to the bar by extension, and equal to that extending the bar in length, might diminish its strength by a function of $\sqrt{2} : 1$. Mr. P. W. Barlow's "Experiments on the Existence of an Element of Strength in Beams," &c., arising from lateral action of the particles (Proceedings of Royal Society, vol. vii., p. 319), as well as Vicat's (Ann. de Chim.), bear upon this obscure subject, upon which experiments are

much to be desired in relation to the construction of artillery; for, whatever be the law or amount, of decrease of strength, as against the bursting strain, due to the coincident longitudinal extension and normal compression, there seems enough already known to warrant the supposition that the reduction is often serious, and that it may be much and unnecessarily increased, by an injudicious position given to the trunnions, and by their rigid fixation, into massive and unyielding metallic gun-carriages. And, as the longitudinal strains are a minimum, when the gun is not sustained on trunnions, but is supported along its whole length, and the recoil firmly resisted, by a fulcrum behind the breech (like the barrel of a musket in its stock), so there can be little doubt that a gun mounted in this form will resist the largest charge in proportion to its scantling and material, or, with any ordinary charges, will last the longest. Thus the cumbrous cannon of ancient times, whether accidentally or not, possessed in this respect another element of strength. (Note A, " Ancient Serpentines.")

32.—*General Comparison of the Constructive Constants of the Materials for Ordnance.*

264. Having thus considered in succession, the relational characteristics of each of the four chief materials for the fabrication of artillery, and some of the most important specialties that belong to each, we arrive at a point where, in the four following Tables, are presented in one view the principal deductions which the discussion warrants :—

TABLE XIV.

Of the Physical Properties of the principal Materials of Construction for Artillery, from British Data.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
No.	MATERIAL.	Ultimate Resistance to		Immediate Resistance within Elastic Limit.		Mean Extension per ton per square inch within.	Mean Compression per ton per square inch within	Final Extension at the Elastic Limit.	Modulus of Elasticity.	Modulus of Elasticity ϵ	Coefficient of *vis viva* of Elastic Resistance T_e.		Coefficient of *vis viva* of Rupture T_r.		Modulus of Force Transmission.
		Tension.	Compression.	Tension.	Compression.	Limit of Col. 5 in terms of L.	Limit of Col. 6 in terms of L.	In terms of L.	L_e	In Pounds per square inch.	Tension.	Compression.	Tension.	Compression.	Feet per second.
		Tons.	Tons.	Tons.	Tons.				Feet.	lbs.	Dynams.	Dynams.	Dynams.	Dynams.	Feet.
1	Gun-Metal, .	16	12 ?	4·5	3 ?	·000230	?	·00104	2,790,000	9,873,000	5·24	?	65·94	?	8260
2	Cast-Iron, . .	10	45	4·0	20 ?	·000220	·00018	·00088	5,750,000	18,400,000	3·94	80·64	24·64	110·88	11100
3	Wrought-Iron,	27	16	12·0	12	·000100	·00010	·00120	7,550,000	24,920,000	16·13	16·13	81·64	48·40	12083
4	Steel, ...	49	60 ?	16·0	17·5 ?	·0000375	?	·00060	8,530,000	29,000,000	10·75	?	92·55	113·33?	14108

NOTE.—The moduli of Elasticity are Tredgold's. The values of i, from the means of various experimenters, as also the values of columns 3, 4, 5, and 6.

Table XV.

Comparison of Weight, Strength, Extensibility, and Stiffness; Cast-Iron being unity, within practical limits, to Static Forces only.

Material.	Weight for = volume.	Strength.	Extensibility.	Stiffness.	Torsion.
					Resistance.
Cast-Iron, . .	1·00	1·00	1·00	1·00	1·00
Gun-Metal, .	1·18	0·65	1·27	0·53	0·55
Wrought-Iron,	1·07	3·00	0·45	2·20	1·11
Steel, . . .	1·07	4·75	0·32	3·15	2·11

The torsion from Colomb and Tredgold's results.

Table XVI.

Molecular Properties of the principal Materials for Construction of Artillery.

1	2	3	4	5	6	7	8	9	10	11	12
Number.	Material.	Chemical Constitution.	Specific Gravity.	Relative Torsion of Rupture.	Temperature of Maximum Strength.	Coefficient of Expansion for 150° Fahr.	Specific Heat.	Coefficient of Conduction for Heat.	Relative Hardness.	Relative Resistance to Abrasion.	Relative Oxidation in moist Air.
			Mean.	Degs.				?	?	?	
1	Gun-Metal, .	$Cu_{17}+Sn$	8·450	367°	32°	·001816	0·110	236?	5	10·5	·10?
2	Cast-Iron, . .	$Fe.C+C'+m$	7·200	52°?	300°?	·000893	0·134	100	10	39·4	·42
3	Wrought-Iron,	$Fe.C+m$	7·750	330°	360°	·000984	0·109	110?	20	322·6	·54
4	Steel, . . .	$Fe.C$	7·800	200°	?	·001225	0·109?	100?	40	968·4	·56

Col. 11, = hardness × T_e.

Col. 12, from the Author's experiments, Trans. Brit. Ass.

Table XVII.

Comparative Financial Relations of the principal Materials of Construction for Artillery.

1	2	3	4	5	6	7	8	9	10	11
Number.	Material.	Average Cost per Ton in Guns in England.	Relative Section for equal strength.	Relative Weight for equal strength.	Relative Money Value for equal strength.	Relative Money Value for equal weights.	Relative Durability in Service where never overstrained.	Unserviceable value as old Material per Ton.	Loss per Ton on the first cost.	Relative Costliness, Capital and Durability included.
		£						£	£	
1	Gun-Metal, .	160	1·60	1·880	5·33	10·02	4	60	100	251·00
2	Cast-Iron, . .	30	1·00	1·000	1·00	1·00	1	4	26	100·00
3	Wrought-Iron,	60	0·33	0·354	2·00	0·70	22	6	54	3·25
4	Steel, . . .	180	0·21	0·226	6·00	1·36	156	15	165	0·87

Note.—Cast-Iron is taken as unity throughout.

The relative strength is as opposed to static forces.

The relative durability takes account only of abrasion and corrosion.

Col. 10 = col. 6 × reciprocal of col. 8.

265. The first of these Tables (Table XIV.) embraces results sufficiently within the limits of extreme experiments to be reliable in practice. The blanks and interrogations in some of the columns, especially as regards gun-metal, indicate how little the attention of experimenters has been directed as yet, to answer the many important questions, needed to fix upon an exact foundation the principal data for fabricating cannon of that material. (Note S.) We perceive, however, how completely the fancied superiority of steel, as a material for ordnance, vanishes, on comparing columns 11, 12, 13, and 14; and that, with properly proportioned guns under service charges, *wrought-iron stands superior to all other materials—three times stronger than gun-metal, four times stronger than cast-iron, and about one-third stronger than steel;* while at the ultimate strain of rupture, it is not far below steel, double as strong nearly as cast-iron, and about a third stronger than gun-metal; the forces being in all cases impulsive.

In Table XV. the general distortibility of the four metals, is compared with cast-iron as unity; and here again the superiority of wrought-iron is apparent.

In Table XVI. various molecular conditions for the same metals are compared, and as in the preceding Tables, the conditions of strength, so in this, those of durability, and of those conditions in service, discussed in the earlier part of this work, are put in comparison.

266. While lastly, in Table XVII., the results are brought to the test of money value. We find that *wrought-iron guns are more than five-fold as durable as those of gun-metal, and twenty-two times as durable as those of cast-iron,* without taking any credit, whatever, on the side of wrought-iron, for the deterioration of cast-iron due to mere repetition of discharge, as referred to in chap. 17; while the first cost of wrought-iron guns (at a large estimate), is not more than double, that now paid for cast-iron, and immensely below the price of either gun-metal or steel; and, *taking first-cost and durability together, gun-metal cannon, are about seventy-seven times, and cast-iron guns, about thirty times, as dear as wrought-iron artillery. Again, the cost of horse-labour, or other means of transport for equal strength (and of course, therefore, for equal effective artillery power) is above five times as great for gun-metal, and nearly three times as great for cast-iron as for wrought-iron guns.* This last consideration puts out of view, the assumed necessity, for a determinate large dead weight in guns, for the mere purpose of

absorbing recoil,—a necessity by no means self-evident, and to the consideration of which we have adverted. (Note T.)

In every respect, then, in which we have submitted them to a comparison, searching and rigid, and that seems to have omitted no important point of inquiry, wrought-iron stands pre-eminently superior to every other material for the fabrication of ordnance.

But we have also indicated grave difficulties, incident to the forging of large masses of wrought-iron, and hence, apparently insuperable obstacles to the use of wrought-iron, even for guns of the largest caliber at present in use, much less to the extension by its means of the magnitude of our artillery, far beyond anything yet attempted, at least in modern practice.

We proceed, then, to consider how these difficulties can be met, and to determine the conditions under which wrought-iron may be applied to the construction of artillery, so as at once not merely to escape, the evils and vast expenditure, of immense single forgings, but also to enable the whole strength of wrought-iron of the best quality, and in its most advantageous state of aggregation, to be applied.

33.—*Of the proper Construction, in Wrought-Iron, of Guns of the largest class.*

267. In the preceding pages it has been shown, that the difficulties of manufacture in wrought-iron, incident to changes in its molecular condition, commence at the point where the rolling process must be abandoned, and give place to forging and hammering (chap. 25). That the frontier of this limit is capable of being largely extended, will not be doubted by practical ironmasters (sect. 215). With existing methods and machinery, however, the production of wrought-iron guns, by means of the rolling process, must stop at about 12-pounders, or a caliber of 4·62 inches.

268. Wrought-iron guns, up to 6-pounders, indeed, may be successfully produced almost by any process of careful forging by hand, with good iron, as the beautiful little Turkish guns, forged at Erzeroum, in the Exhibition of 1851, well showed ; and others, made more than thirty years since, by the author's father, carrying 3 lbs. lead spherical shot, for the boat use of the Coast-guard Service,

from designs by Capt. Pottinger, E.I.C.S., and which were probably the very earliest British successful attempts in producing forged cannon in one piece, fired by a lock. The chambered breeches of these guns were of soft steel, screwed into the chase ; they were fired by a lock, united with a prolongation of the breech, which ended in a sort of pistol-formed directing handle, and being beautifully balanced on trunnions and a vertical spindle, were directed and fired, from the bow of a boat, by one hand and finger on the trigger, with the facility and accuracy of a shoulder rifle, so that an object in rapid motion could be followed and struck, almost as a sportsman follows a bird upon the wing. Some of these guns were rifled, and the range of all, from the small windage and the density of the lead shot, was surprising, and their practice extremely accurate. With the adoption of the Minié form of shot in hardened lead, it can scarcely be doubted that the use of wrought-iron guns of this form, for light horse artillery, would confer a celerity of movement and of practice, combined with range and power, that would be of the highest value in many instances, and more particularly against a mobile and numerous cavalry.

269. To return from this digression,—the capabilities of the rolling process for producing tubes of wrought-iron, of enormous strength in relation to thickness, are well known now to mechanical engineers, since the introduction, some years ago, of the patent process of welding wrought-iron tubes, by rolling at a welding heat, upon a maundrell, either a single, or two flat and equal strips of boiler-plate, which thus become united at the edges by one or by two longitudinal welds. This constitutes the process of the Birmingham Patent Tube Company, whose tubes are extensively used for steam-boilers and many other purposes all over the world.

270. No series of accurate or comprehensive experiments has yet been made as to the relations between diameter, thickness, and strength of these, or indeed any other, tubes, though much to be desired. The author has, however, been obligingly furnished with some results of experiments made specially for him, by the proprietors of these works, of which a few are subjoined, and which prove the enormous resisting powers of these tubes to internal pressure, applied by water, in a very striking manner. (Note U.)

TABLE XVIII.

Experiments on the Strength of Wrought-Iron Tubes.

Internal Diameter of Tube.	Thickness.	Pressure per square inch, withstood.	Pressure in Tons per square inch.	Extension in Circumference under the Strain.	Bursting Pressure per square inch.	Bursting Pressure in Tons per square inch.
Inches.	Inches.	lbs.	Tons.	Inches.	lbs.	Tons.
3·500	0·25	6742	3·01	·033		
3·625	0·1875	2316	1·03	·025		
3·750	0·125	2316	1·03	·150		
3·250	0·125	3920	1·30	·050	4825	2·15
2·750	0·125	2543	1·13	·031		
2·250	0·125	6182	2·76	·050	7690	3·43
1·250	0·125	8897	3·97	insensible.	Exceeds the power of the pump.	

It will be recollected that these tubes are rolled chiefly to resist *external* pressure, that the fibre of the iron in them, is all parallel to the axis, or longitudinal, and the line of welding in the same direction; hence, their conditions of manufacture are the most unfavourable possible for effective resistance to internal pressure: and yet, their powers are enormous. The actual static pressure withstood by a tube of about the caliber of a 6-pounder, and of only *a quarter of an inch thick*, being, perhaps, about half the maximum pressure produced by discharge upon that gun. The causes of this superiority have been already fully developed (chaps. 22, 23, and 24), and are dependent on the simple fact, that these tubes *are rolled*, and not hammered, and if such results are obtained with a very inferior and almost careless mode of manufacture, what might not be produced were its objects directed, not merely to tubes sufficiently good to resist the moderate pressures, to which their marketable uses alone expose them, and to their production at a moderate market price,—but to the production of rolled tubes of large caliber and thickness, of the finest and toughest iron, and whose fibre should be uniformly arranged spirally round the axis, like the twist barrel of a fowling-piece (sect. 218), and specially prepared for cannon.

271. There can be no doubt, therefore, that by suitable modifications of the rolling process, and a judicious selection of the iron, tubes could be rolled for forming guns of all calibers, up to 12-pounders at least, possessing enormous resisting powers, great extensibility within the elastic limit, and hence, great safety in service, and at a cost perfectly insignificant as compared with any

previous mode of manufacturing wrought-iron artillery. The molecular condition of the iron and its coefficients of strength would not become impaired, until after a thickness of from 2 to 3 inches of metal had been reached.

The problem, therefore, seems within easy reach, as respects small calibers, and these would be the materials from which to form a wrought-iron field artillery. (Note V.) But the question remains, how are all the larger and heavier, and, perhaps, much more important calibers, to be safely produced in wrought-iron? Here, production in single masses seems nearly impracticable, even if our machinery of production were increased to the magnitude and power, requisite to enable rolled masses of the necessary size to be attained; for the length of time alone indispensable, to both the heating and the cooling of those huge pieces, inevitably results in changes of molecular structure of an injurious character (chap. 23) to the metal.

272. We are, therefore, limited to the use of such forms and such dimensions of iron as can be rolled with determinate direction of fibre, and of such dimensions, as shall be heated and cooled with the required rapidity.

The larger calibers of wrought-iron ordnance must, therefore, be built up in separate pieces, and in such a manner, that the tangential, and the longitudinal stretching strains, shall be resisted, each by masses, whose directions of fibre (or crystals), and therefore whose maximum elastic extension shall coincide with these directions respectively.

We are now to analyze these forces, and consider how this combination may be effected, and whether the necessity of combining a number of separate pieces to form the whole body of the gun is attended with advantage or disadvantage to its materials, in resisting the forces produced by the explosion of the charge.

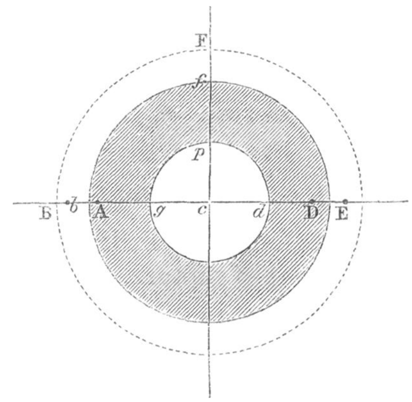


Fig. 1.

273. Let the shaded portion A, *f*, D, be the transverse section, and a unit in length, of a gun formed in one mass. The pressure of the elastic fluids of the explosion, acting upon the interior of the cylinder, is resolved in at least three distinct directions of forces acting upon or within the metal of the gun, and tending to produce as many distinct distortions.

1°. A tangential pressure producing a splitting strain, in extension, perpendicular to the radius.

2°. A compression of the metal in the direction of the radius, which adds to the extension due to the tangential strain, and is greatest at the interior surface, g, p, d.

3°. A longitudinal strain producing extension, parallel to the axis, and nearly equal for any part of the same transverse section of metal. Both the latter forces tend to increase the effective energy of the first.

The measure of tension at the interior circumference, is the pressure per square inch, times g, d. But, in accordance with Hooke's law, *ut tensio sic vis*, the resistance opposed to this pressure, by the extensible and compressible elastic metal, is proportionate to the pressure, which is greater for the interior lamina of metal than for any other further removed from the axis. The metal, therefore, of the interior of the gun is the most stretched, and the resistance afforded by any two successive laminæ, whose distances from the axis are D' and D, are as D^2 to D'^2.

The exterior portions of the solid thickness of the gun bear proportionably, therefore, but a very small share of the strain from the exploded charge.

Were the nature of the material by possibility such, that its measure of tenacity were accompanied either by infinite extensibility, or by none at all, then the measure of resistance would be the same for each successive, indefinitely thin lamina, and would be simply equal to the entire cross section of metal, or to twice p, f.

274. The limit, therefore, at which no addition of thickness to the exterior of a gun adds anything to its resisting power, is reached as soon as the maximum pressure per square inch upon the interior equals the resistance of its metal at the point of rupture, for at this point the interior laminæ tear asunder, while those exterior to them remain whole, to be in succession ruptured by a further application of pressure, which now acts with a greater moment, because upon a greater internal diameter, by the depth of the rent opened, added to the caliber. This result is indicated by every formula proposed for the resistance of cylinders under pressure.

$$e = \frac{D''p}{2R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{Morin.} \qquad (1)$$

$$e = \frac{D''p}{R} \times \text{hyp. log.} \left(\frac{1 + a + \frac{p}{R}}{\frac{1}{2} + \frac{p}{R}} \right) \quad . \quad . \quad \text{Dr. Robinson.} \qquad (2)$$

$$e = \frac{D''p}{R} \times \text{hyp. log. } 2, \quad . \quad . \quad . \quad . \quad . \quad \text{Dr. Robinson.} \qquad (3)$$

Each on a different assumption as to the nature of the molecular forces under strain, and the mode in which fracture occurs.

$$e = \frac{D''}{2} \times \left(\sqrt{\frac{R+p}{R-p}} - 1 \right), \quad . \quad . \quad . \quad . \quad . \quad \text{Dr. Harte.} \qquad (4)$$

$$e = \frac{D''p}{R-p}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{Barlow.} \qquad (5)$$

e being the thickness of metal, D'' the internal diameter, or the caliber, R the coefficient of rupture of the metal, and p the maximum pressure on the unit of interior surface in each case; a in equation 2 being the fraction of D'' that determines the point in the radius, round which the motion at rupture is supposed to rotate.

275. Professor Barlow, who was the first to point this out, in his paper on the strength of hydraulic press cylinders (Trans. Ins. Civ. Eng., vol. i.), remarks that the result is apparently paradoxical. He has, however, himself produced the apparent paradox, by not drawing quite the correct conclusion from his own investigation, for it is not true to say, that no addition of thickness adds anything to the strength of the cylinder, but that no addition of thickness will prevent the rupture of the interior, as soon as the pressure per square inch reaches the point of final extensibility of the metal at the internal surface.

276. If D'' and p be given, the value of e for different materials depends both upon the absolute tenacity of the particular metal and upon its extensibility. The thickness at which rupture internally will commence, is as the final tenacity directly, and as the final extensibility inversely; the limit of thickness, therefore, is in proportion to $\frac{\epsilon}{R}$ for each material, from which it follows that, the thickness

at which any further addition of metal will be useless, will be sooner reached with a gun of cast-steel, than of any other applicable material—a deduction full of important considerations, as respects the use of this supposed valuable metal for artillery.

277. Professor Barlow, in common with other investigators, assumes the gun to part in two, at opposite ends of a diameter, at the same moment. This is seldom, if ever, the case in reality, as we have seen (sections 7, 8) that in practice, one part or other, is slightly defective, or weaker in some way, and that fracture begins and takes place from one side; for example, from D, the gun opening out and turning out round a point A, as a fulcrum, at the opposite side and very near the exterior surface.

There is, therefore, a moment to the forces of pressure and of resistance, the former being $Dx \times Ac$, and the latter $ct \times AD$; but this does not alter the condition upon which the limit of rupture depends; for if a farther thickness be added to the gun, so that its external surface reaches the dotted line BF, increasing its thickness from f to F, the relation of the moments is unchanged, or

$$Ac : bc :: AD : bE,$$

with some slight change, however, in the position relatively, both of the centres of resistant effort D and E, and of the fulcra of rotation A and b.

278. Let us, however, now suppose a new condition. Let it be assumed that the caliber of the gun, g, d, continues the same, and the maximum pressure per square inch likewise, that the annular shaded space between the circles A, f and g, p, were filled up with some perfectly hard substance, possessing perfect mobility of its particles (as if it were filled with a fluid, for example, which could be confined so as not to flow away), and that outside this, between the circle A, f, and the dotted circle B, F, the annular space, represented the section of a surrounding cylinder, of the same material as the gun was made of before.

The effective resistance now produced by the square inch of metal is considerably increased, merely by removing it further from the axis, and interposing the thickness p, f of *inert material;* for the internal pressure per square inch remains the same as before, but its energy to extend the metal is reduced in the ratio of A, D : b, E.

279. Again let g, d, Fig. 2, be the caliber of the gun, as before, and g, A its thickness, and let us assume this divided into a number of separate, closely fitting concentric cylinders, 1, 2, 3, 4, 5, 6. Let e or D be the middle point between the external and internal surfaces of the gun, and let us suppose that from the interior cylinder 6 to the exterior 1, these have been in succession so superimposed, that the three interior cylinders 4, 5, and 6, are in a state of compression, while the three external ones, 1, 2, and 3, are in a state of extension, each set re-acting upon the other in virtue of the elasticity of the material, just like so many extended rings of Indian rubber, tightly grasping round the same number of already compressed hollow cylinders, of the same material. In this state of things, let us suppose pressure applied to the interior of the gun by discharge. Its first effect is to act upon the internal compressed cylinders in succession, which are in the state of so many compressed springs, and to relax their compression by extending their circumferences until they have successively reached their respective normal lengths, of uncompressed molecular equilibrium; but in doing this (as all the rings are absolutely in contact), a certain amount of extension has been necessarily produced upon the three outer rings, which are now in the condition of springs before slightly, and now still more, extended. At this moment the elastic forces of the three internal rings begin to react upon the pressure, as effective resistances to extension also, and the state of things is such that the *whole* section of the metal of the gun, represented by the six rings, has got into a state of equable extension, and offers effective resistance to the pressure. But, although the interior rings are, as always must happen, subjected to the greatest pressure per square inch of their circumferences, they are not in this case the most extended, or extended in proportion to the intensity of the pressure, because we commenced applying the pressure to them, while they were in a state of compression.

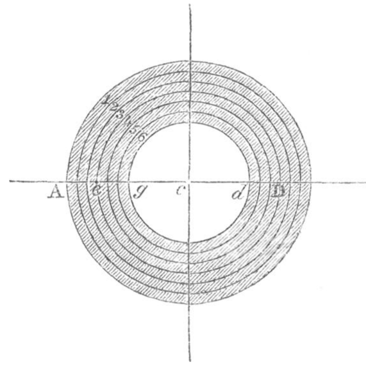


Fig. 2.

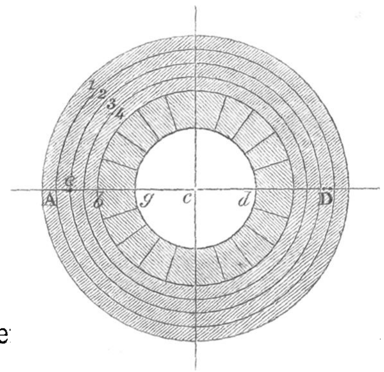
280. We have thus been able in some degree to equalize the extension of the three exterior and of the three interior cylinders; but if we had been able in the first instance to cause each successive cylinder to grasp and compress the pre-

ceding ones within it, with a force inversely proportionate, to that with which it will be afterwards extended, we should have attained, *at a certain pressure*, a perfectly equal extension for all the successive cylinders, so that their united resistances might be considered as centered in the middle point e or D, and hence that the whole section of metal due to the gun's thickness from g to A would be equally effective, in resisting the internal pressure, as though its resolved forces, produced a straight pull on the tangent at e, perpendicular to A, D, and that the metal of the gun were a straight bar, of the breadth A, g, and unit of depth, resisting in the opposite direction, but in the same line. That this should be perfectly true theoretically, the number of successive cylinders must be infinite, or the thickness of each infinitely small, in which case it may be shown that for a given total thickness of gun, the strength of that divided into successive annular laminæ will be increased, over that whose thickness is in one solid annulus, in the ratio of

$$\frac{D'-D''}{D''} : \frac{D'^2-D''^2}{D'^2+D''^2},$$

D' being the external and D'' the internal diameter of the gun. For any practical purpose, however, it is sufficient to divide the total thickness, into six or eight parts; and the requisite compressions of the internal cylinders by the extension of the external ones, may be practically and readily produced, by shrinking them on upon each other, at high temperatures, in the way that wheel tyres are shrunk-on; to effect this in practice the length of the external cylinders must be not very great.

281. Lastly, combining all that we have said of Fig. 1 and Fig. 2,—if as in Fig. 3, g, d be as before the caliber of the gun; that we interpose a certain annular thickness g, b, of merely hard inert material, such as a number of longitudinal prismatic bars of metal, parallel to the axis of the gun, and forming a cylinder of equal voussoirs, and grasp these externally, by a set of successive closely fitting cylinders, whose total thickness is A, b, and of which the inner half of their total number (3 and 4) is in a state of compression, while the oute



of extension:—we have a state of things in which the total section of resisting material, A, *b*, shall be operative against the internal pressure, to the highest possible advantage, for—

1°. We have reduced the moment of strain per square inch of the metal of *all* the cylinders, 1, 2, 3, 4, by removing them further out from *c*, the axis.

2°. We have equalized the extension, in relation to the maximum pressure, upon all parts of the metal from *b* to A, so that, it all re-acts alike, with an equable strain, and as though subjected to an ordinary straight pull.

282. We have now arrived, therefore, at a built-up gun of wrought-iron, in which the external cylinders, *A*, *b*, as they cannot practically be superimposed and closely fitted, in the required conditions, if consisting each of a single piece equal to the whole length of the gun, must consist of a number of comparatively short rings, applied end to end. The longitudinal strains due to the projection of the ball or to the recoil, as well as to the coherence of the whole together, must, however, be provided for, and for this the internal longitudinal voussoir prisms, *g*, *b*, are efficient; or a cylinder in one piece may (if not too thick) be substituted for these voussoirs.

A gun or mortar thus formed will consist of one or more plies of longitudinal bars extending the whole length of the gun, and fitting closely at the edges, forming by their internal surfaces (when together), the cylindric cavity of the chase, upon which a number of circular rings will be closely fitted by shrinking-on, at a suitable heat; and upon these again, other rings (breaking joint of the abutting edges), until the necessary strength be reached. Various modes of closing the breech end are practicable; but into these or other questions of merely operative detail, it is not my purpose here to enter, as we are dealing with principles, though not losing sight of practice. The theory of the strength of guns thus built up, and the methods of calculating their proportions, will be found in Note W. Some subsidiary questions remain to be here considered.

283. In guns thus constructed, the whole of the normal bursting strains are sustained by the external rings,—their total strength having been determined for the maximum pressure per square inch, regard being had to the proper limited

value of i, for often repeated, impulsive strains, as derived from sect. 110; the strain upon the internal longitudinal bars will be derived from equations 6 and 7, sect. 91, and from the principles enunciated in chapters 18 and 31; and hence the total transverse section of these bars, all of which are strained alike.

284. The relation between the longitudinal and the tangential strains, for a given internal maximum pressure, depends upon the thickness of the portion of the gun resisting the latter, and upon the caliber.

From equations 1 and 2, $e = \frac{D' - D''}{2}$, (65)

If we assume such a length of the gun in the line of the axis l, that

$$D''l = \frac{\pi D''^2}{4}$$

and hence $$l = \frac{\pi D''}{4}. \tag{66}$$

The strains, both longitudinal and tangential, upon this segment of the length of gun shall be equal in amount.

But the forces to resist these separately, are proportional to the total section of metal in the transverse section of the gun, and in its longitudinal section due to the length l; and these are

$$\frac{\pi}{4}(D'^2 - D''^2) = \pi e\,(D'' + e), \text{ and} \tag{67}$$

$$2le = \frac{\pi D''e}{2}, \tag{68}$$

which bear to each other the ratio of

$$D'' + e : \frac{D''}{2} \text{ or of } 2\left(1 + \frac{e}{D''}\right) : 1,$$
$$\text{or of } 2 + \frac{D' - D''}{D''} : 1;$$

and this is the proportion that the total resisting power of the external rings must bear to that of the internal longitudinal bars at a minimum; but, for the purposes of reducing the maximum strain upon the former, by removing them further from the axis, it will often be convenient and advantageous to give a

greater thickness to the voussoir bars, or to the single cylindric tube which may constitute the interior of the chase of the gun.

285. In guns cast or forged solidly, of one piece, and of the usual proportion of one caliber in thickness,

$$e = D''$$

and

$$D' = 3\ D''$$

and the areas of resistance on the length l, are as 4 : 1, which is the ratio of the tendency to longitudinal rupture, to that for transverse rupture, in guns of the established models.

286. It is indispensable, that the radial joints between the voussoir bars, be made originally closely fitting, and that the total extension of the external rings, at the moment of maximum pressure, be not such, as shall sensibly open them, so as to admit the momentary pressure of the elastic gases of the powder between; if this happen, it is practically the same thing as if the caliber of the gun were, for the instant, enlarged by an increase of diameter, equal to twice the thickness of the longitudinal bars, and the bursting strain may be thus greatly increased, in the same way, as fracture, once begun in the interior of a solid cast gun, adds its own depth to the diameter of the piece, as affected by the bursting strain (sects. 3 and 4, and Note X). This may be best secured by dividing the internal longitudinal bars into two equal thicknesses, one within the other, breaking joint longitudinally, so as to diminish the radial depth of the abutting joints of the innermost bars, which alone in this case can receive any pressure from the explosion.

287. Thus arranged, and with a properly proportioned strength of gun, this difficulty may be fully provided against; for example, in a 10-inch gun, thus made, assuming the mean circumference of the external shrunk-on rings to be a little more than 6 feet, their total extension at the instant of its maximum (which will be *after* that of maximum pressure) should not exceed $\frac{1}{6000}$ of their total length, = ·012 of an inch; and supposing the whole circumference divided into 15 equal voussoirs, or bars, the extent of opening for the instant between each would be ·0008 of an inch, *less* the lateral extension of each voussoir, produced by their compression in the normal, under the force. This will probably be about

one-third as much, leaving the opening at the instant between one voussoir and the next only ·00027 of an inch. The amount of opening, therefore, would be so evanescent, as to preclude the transference of any elastic pressure, into tangential force, between the joints. Mechanical engineers, best competent to judge of the question, will not hesitate to admit, that with the accuracy and power of precise repetition of similar regular forms, which we now possess, in the lathe and planing machine in their several modifications, no real difficulty exists to the perfect formation, and scrupulously exact fitment, of these longitudinal bars and external rings, at a very moderate cost. Indeed, Mr. Whitworth has already actually accomplished incomparably more difficult forms and fittings, in the internal longitudinal shell, and external rings, of his patent rifled cannon; which, in the principles of its design, however, differs altogether from that of the construction here proposed, inasmuch as the interior longitudinal shell of his gun is formed in three pieces of a single thickness each, and his external rings are also in a single ply or thickness, by which the entire advantage of their separation into laminæ, which would nearly double the strength of the gun, is lost.

288. Solid reinforce rings, indeed, have been repeatedly proposed, and frequently applied to various projects or forms of cannon, but the author believes that the peculiar advantages of their application in thin concentric laminæ, the internal ones of which shall be compressed, by an initial extension, of the external ones, has never before been distinctly pointed out, and their adoption proposed and urged; the essential and radical distinction being this, that by no arrangement or variation of design, can a gun be formed in a single ply of rings whose strength to sustain an internal pressure shall be greater than the cohesive power of the material per square inch of section; whereas, by the subdivision of the rings into a number of superimposed plies, each compressing those within it, the strength of the gun may be increased so as to bear an internal pressure, any required number of times greater than the ultimate cohesive power of the material; in fact, may be increased *ad infinitum.*

289. The investigation (in Note Y) may appear to render the operation of shrinking-on the subdivided rings in succession, a very delicate and difficult one; and so it would be, were it in practice necessary to take any very precise account of the temperature at which each ring is to be placed upon the previous one;

but, as has been already remarked (chap. 10), all writers on Physics have copied each other in the error of inexact physical conception involved in equation 3, sect. 88, which properly applies only to absolutely rigid and perfectly elastic solids, to which even iron in its cold state only approximates. Iron softened, and rendered ductile, by a high temperature, however, is no longer in the same condition.

290. For example, the contraction of a wrought-iron bar of an inch square is about $\frac{1}{10.000}$ of its length for a change of temperature of 15° Fahr., and a mechanical strain of one ton produces about a like extension; and this continues nearly true for both, throughout whatever range of temperature and of strain, while the molecular structure of the bar remains the same; but if the bar be heated 900°, or 60 × 15°, it will expand, and in cooling again contract, through rather a greater range than $\frac{60}{10.000}$ of its length; yet it does not follow, that after its cooling and contraction, a strain of 60 tons will remain upon the bar at its extremities, if their approach be prevented: it is impossible,—for the total power of the bar (1 inch square) to resist rupture, is only from 14 to 30 tons, at most.

291. What, then, does happen? The bar, heated until its molecular condition is altered, and part of its rigidity gone, and replaced, by a new state of ductility and softness, amounting in the extreme case almost to plasticity, is no longer in a condition to *transmit* the force of its own contraction, and the latter is expended, not in labouring force at the extremities, but in work done in elongating the bar itself, whose length becomes permanently increased, and in altering its form, and the effort finally expended upon the extremities, is only the *residual strain*, or difference between the total force of contraction, and that already expended in altering the length (and with it the other dimensions) of the bar. Thus, the experiments of the Franklin Institute upon the tenacity of wrought-iron at various temperatures proved that—

At 800° to 900° Fahr.	$\frac{1}{4}$
1050° „	$\frac{1}{2}$
1240° „	$\frac{2}{3}$
1317° „	$\frac{7}{10}$

of the maximum tenacity of the metal, at ordinary atmospheric temperatures, were destroyed; while at 3945°, its fusing point, according to Clement and

Desormes, its tenacity sinks to zero. So that, if we take the normal strain of rupture, for good wrought-iron, at 24 tons per square inch, the proportion in which the total contractile force is divided, between contractile strain at the extremities after cooling, and elongation of the bar previously, is—

Temperature.	Known to Workmen as	Effort of Contraction.	Effort of Elongation.
Fahr.		Tons.	Tons.
800° to 900°	Black-red.	18	6
1050°	Low-red.	12	12
1240°	Bright-red.	8	16
1317°	Yellow.	7	17
3945°	White.	0	0

292. All which, is in perfect accordance with the principle, *ut tensio sic vis*. This indicates, therefore, that in practice, there is no objection to shrinking-on the successive rings, at temperatures much higher than theory, based on the usual incorrect view of the relation of expansion and contraction by heat to the molecular constitution of metals, would fix as the limit; besides which, the most simple means are at hand, to regulate to any extent the final tension of each ring upon the preceding one; for, if the internal and external diameters of any two rings to be superimposed, be made such that, when heated to the previously fixed upon temperature, they shall be precisely alike, the tensions and elongations shall bear to each other the ratios of the preceding Table; but it is in our power, to make the internal diameter of the outside ring exceed the external diameter of the inside one, when both are at this temperature, by any small fraction we please, and thus permit a certain amount of *unresisted contraction* to occur in the outer ring, when superimposed, before it finally grasps, and begins to compress the inner one, and thus, with perfect practical facility, all the rings of any series, however large or numerous, may be shrunk-on over each other, and caused to produce any assignable degrees of extension and of compression, (within the possible limits), and yet all the rings be shrunk-on at one temperature, and that one a full red heat.

293. This latter temperature would seem more advisable in every instance, than one considerably below it, at least than any one below a low or "cherry-red" heat, however small may be the amount of final contractile strain desired; for at or a little below this latter temperature, the molecular condition of

wrought-iron certainly undergoes a sudden change, and the rapidity of increase of the rigidity of approaching coldness, is such, that the mechanical strain brought upon the metal, is likely to produce rupture, for the heat is sufficient to diminish the tenacity of the material, though not to much increase its ductility. Rings shrunk-on upon each other, therefore, at temperatures under 1100° Fahr. should be placed in an annealing oven, to cool with greater slowness. The best practice, however, will be, to shrink-on every ring upon the preceding (with the necessary allowance for external and internal diameter), at a full red heat, say from 1200° to 1300° Fahr., in which case, the metal may be safely permitted to cool at the ordinary rate in air, or may be even suddenly cooled by plunging into water, without danger of rupture.

294. It does not admit of question, that this general method of construction, for cylinders exposed to great internal pressure, admits, from its practical facility of execution, of numerous other valuable applications, as well as to guns; for example, to the cylinders of hydraulic presses, for which wrought-iron, *thus* applied, would afford a valuable, trustworthy, and economical substitute for cast-iron, which the history of the Britannia and Conway Bridges, and many other instances, have proved so impossible to rely upon.

295. It has been stated that wrought-iron rings, thus shrunk-on at a sufficiently elevated temperature, may be cooled suddenly with impunity. Such is, in fact, the general practice with mechanical engineers in shrinking-on the tyres of the wheels of locomotive engines, and of other railway wheels; and for these purposes, provided a safe amount of tenacity remain in the tyre to provide against the effects of centrifugal force, and of accidental blows and strains, the harder and less extensible the tyre the better (although some lamentable accidents in the flying off of driving-wheel tyres prove that this is not always insured),—but for application to the construction of artillery, it is never to be commended. The value of a long range of extensibility, in the material for ordnance, has been already fully proved. Wrought-iron will be brought into use for this purpose to the most advantage, when we preserve this the greatest—when, in fact, it is in a state, presenting the yielding extensibility of gun-metal, in combination with the resilience and higher tenacity, which are its own. These constitute the real merits of wrought-iron, as a material for ordnance, and it shares them in no respect with steel, or with any other known material.

We shall elicit these properties most fully, when the wrought-iron applied has been slowly cooled—in other words, has been *annealed;* and this necessarily happens, when the shrunk-on rings are permitted to cool slowly, while, (with many classes of hard "steely iron," like the Swedish, if suddenly cooled, an approach, more or less complete, is made) to the brittle and dangerous condition of hardened and untempered steel.

34.—*Of the Relations between Annealing and Tenacity.*

296. It will be desirable, therefore, to make some remarks on the subject of annealing wrought-iron,—one upon which our experimental information is deplorably deficient.

That the condensation, produced by "hammer-hardening," and, still more, the longitudinal arrangement of crystal induced by lamination, rolling, and wire-drawing, considerably increase the longitudinal tenacity of iron, copper, and several of the alloys of the latter, is certain. The evidence of it is most remarkable in the case of fine brass wire, which, when hard from the draw-plate, closely approaches wrought-iron in tenacity, resisting, according to Baudrimont, to 87,000 lbs. per square inch. On the other hand, that "annealing" is attended with a greater or less loss of tenacity, appears to admit of little doubt; but to what extent this loss reaches, in proportion to the temperature, &c., still requires additional experimental investigation; for the experiments hitherto made, appear only to have had regard to the absolute final force required for rupture, and to have taken no note of the *increased range* of extension, induced by the annealing. Yet, upon both of these, the "work done" in producing rupture depends, and it may not improbably be ultimately found, that the coefficient T_r, is not altered at all by annealing, but is, for the same iron or other metal, a constant, only changeable in the ratio of the factors whose product it is.

297. Even the temperature at which that change of molecular condition which constitutes perfect annealing, takes place, remains yet to be determined, for every metal. There seems to be, at least, a fixed and rather narrow range of temperature, for every metal, without the limits of which annealing does not take place, and the mean temperature within this range appears to be more elevated in proportion as the metal itself has a higher fusing temperature. Thus platina, after lamination or wire-drawing, is not annealed, under an

intense white heat; wrought-iron is perfectly annealed at a clear bright red (about 1200° Fahr., according to the experiments of the Franklin Institute); copper anneals perfectly at a very low red heat, scarcely visible in clear daylight; and zinc at a still lower temperature. Some metals, of very low fusing points, such as lead and tin, probably owe their apparent incapability of becoming hardened by lamination or wiredrawing, to their annealing temperatures being so low, that *the heat evolved* in the process, is sufficient to anneal them, i. e. to prevent that change in the mutual relations of the particles, whether one of distance or of position, upon which hardening depends.

A rich reward awaits the physicist who, in a comprehensive manner, shall first, experimentally, attack the question of the molecular changes produced by hardening and annealing; it has been as yet almost unattempted. As respects the material with which we are immediately engaged,—wrought-iron,—Baudrimont, in a very valuable paper ("Ann. de Chim. et Phys.," t. ix.), appears to have ascertained, that a temperature above that of "cherry red," perhaps, about 1150° Fahr., is necessary for annealing it;—that at a white heat it is almost instantly annealed, and at the same time suffers more or less a change of crystalline structure;—and that a certain amount of tenacity is lost by annealing platinum, iron, copper, and some of its alloys.

298. The changes in volume, or density, induced by mechanical pressure, and by annealing of the same wrought-iron, he found, by some delicately conducted experiments, as follows:—

	Specific Gravity.
Iron wire compressed by the draw-plate, .	7·6305
„ annealed, ...	7·6000
Iron laminated, ...	7·7169
The same, annealed, ...	7·6000
„ laminated a second time, ...	7·7312
„ hammer-hardened, ...	7·7433

His results for copper, which probably, judging from Dussausoy's results, would approximately apply to gun-metal, are as follow:—

Copper, fused and cooled slowly, ...	8·4525
„ compressed by the draw-plate, . .	8·6225
„ annealed, ...	8·3912

Copper, laminated, ...	8·4931
The same, annealed, ...	8·4525
„ laminated a second time, ...	8·4719
„ hammer-hardened, ...	8·5079

The volume, thus, is sensibly increased by annealing, presenting in this a remarkable opposition of fact to steel, whose volume is increased by hardening on sudden cooling.

299. The experiments made by the Franklin Institute, and forming part of its Report on the Strength of Materials for Steam-boilers, to the American Government (1831–1837), although, perhaps, the only systematic ones made, present results so discordant as scarcely to admit of confidence.

It would follow from them, that, in round numbers, wrought-iron, whose strength before being annealed was 53000 lbs. per square inch, becomes 46000 lbs. per square inch after annealing.

They conclude, that the diminution of tenacity is nearly in proportion to the elevation of temperature of annealing, but "were not able to detect any essential change of specific gravity," before and after; they add, that "in some cases the difference between the strength previous to annealing, and that exhibited afterwards was so small, that it was difficult to refer it to any other cause than the original inequalities of structure. These experiments merely related to the force of ultimate rupture, and as no measurements of extension appear to have been made for hard or annealed bars, or at high temperatures, it is impossible to compare the "work done" on the rupture of the same bar in the several conditions. This renders these otherwise careful and elaborate experiments of very little value. A few comparable results (on wires) are contained in a paper by M. Payen (Ann. des Mines, t. vi. 3me ser.) :—"De la puissance mecanique consommé par le tirage a froid des fils," &c. An iron wire having been passed several times through the draw-plate, of one millimetre in diameter, broke with 52 kilogrammes ; having been only once passed through the plate, it broke with 40 kilogrammes ; and having been annealed, it broke with 30 kilogrammes.

300. The elongation at rupture, in the first case, while quite hard, was only $0^{m}{\cdot}004$; after annealing, it was $0^{m}{\cdot}200$ at rupture. The diameter of the wire increases by annealing 0·055. If we attempt to test this by the "work done" to

produce rupture, we find that although the strain is so much less on the annealed wire, the work done to produce elongation and rupture is far greater in it, than in the hard wire:—

$$\text{Hard, } . \ . \ \tfrac{1}{2}(52 \times 0{\cdot}004) = 0{\cdot}104,$$
$$\text{Annealed, } . \ \tfrac{1}{2}(30 \times 0{\cdot}200) = 3{\cdot}000,$$

or in the proportion of nearly 29 : 1,—a result, which, if even approximately correct, gives abundant corroboration of the views herein enunciated as to the value of soft and ductile wrought-iron for artillery. A paper of Baudrimont's, on the diminution of tenacity due to annealing (Ann. de Chim. et Phys., t. 60, p. 78), is deserving of attention here.

35.—*Of Trunnions or other Fulcra, in Relation to Built-up Guns.*

301. In the attempts heretofore made (in modern times), to construct built-up wrought-iron guns in single-ply rings, trunnions have been formed, attached to one of the rings, and the gun has been mounted as much as possible in the ordinary way. It has been already shown (chap. 31) that every gun, whether solid or built up, is weakened by this mode of mounting, but when applied to built-up guns in rings, its effects are fatal; the recoil at every discharge tends to dislocate the rings from each other, and to move them relatively forward upon the internal longitudinal bars; a circumstance that has actually produced the destruction of some such guns tried at Woolwich.

302. Wrought-iron built-up guns of large size should, therefore, for every reason, be so mounted, that the whole force of the recoil should be expended upon a fulcrum placed directly in the line of the axis, and behind the breech, much in the same way as the ancient wrought-iron cannon (bombards, serpentines, and chamber pieces) were mounted (Note A), and that this can be done with perfect facility, and without sacrifice of any of the requirements or advantages of the usual method of mid-length trunnions, probably no competent artillerist or mechanical engineer will be found to doubt; although, because a deviation from the "routine" of some centuries, any such arrangement is certain to meet with opposition in the first instance,—in fact, so far from the abandonment of trunnions being a disadvantage, it would be attended with the immense ad-

vantage of giving facilities for the absorption of recoil by means of elastic material, pressed upon by the breech of the gun, instead of by the crude expedient of mere mass in the gun itself, and thus would permit portability in the guns, and lightness in the carriages, more especially of garrison guns, and other less obvious advantages, not otherwise attainable. This method of dispensing with trunnions, and still permitting elevation and depression of the gun with facility, was actually carried out, with great mechanical skill, in the ancient Serpentine described in Note A.

303. To recapitulate:—The advantages, then, which the method now proposed offers, for the construction of built-up artillery, of wrought-iron, are, as respects the material itself:—

1°. The iron constituting the integrant parts, is all in moderate-sized, straight, prismatic pieces, formed of rolled bars only; hence, with its fibre all longitudinal, perfectly uniform, and its extensibility the greatest possible, and in the same direction in which it is to be strained; it is, therefore, a better material than any forged iron can by possibility be made.

2°. The limitation of manufacture of the iron, thus, to rolling, and the dispensing with all massive forgings, insures absolute soundness and uniformity of properties in the material.

3°. The limited size of each integrant part, and the mode of preparation and combination, afford unavoidable tests of soundness and of perfect workmanship, step by step, for every portion of the whole; unknown or wilfully concealed defects are impossible.

4°. Facility of execution by ordinary tools, and under easily obtained conditions, and without the necessity either for peculiarly skilled labour, on the part of "heavy forgemen," or for steam or other hammers, &c., of unusual power and very doubtful utility; and hence, very considerable reduction in cost, as compared with wrought-iron artillery forged in mass.

5°. Facility of transport by reduction of weight, as compared with solid guns of the same or of any other known material.

304. And, as respects the mode of application,—

6°. A better material than massive forged iron is much more scientifi-

cally and advantageously applied,—the same section of iron doing much more resisting work, as applied in the gun built up in compressed and extended plies, than in any solid or other gun.

7°. The introduction thus into cannon, of a principle of elasticity, or rather of elastic range (as in a carriage-spring divided into a number of superimposed leaves), greater than that due to the modulus of elasticity of the material itself, and so acting, by distribution of the maximum effort of the explosion, upon the rings successively recipient of the strain, during the time of the ball's traject through the chase, as materially to relieve its effects upon the gun.

In a word, we secure better material, and apply it better in place. It is upon these principles that the author has designed for Government the great 36-inch mortars, to throw a shell of a yard in diameter, and weighing in flight above 3000 pounds, which are now in process of manufacture.

305. In conclusion, it will be desirable to offer some remarks, in refutation of the principal objections that have been made, or most obviously present themselves, to wrought-iron guns generally, and to built-up guns, or those formed in several separate pieces, in particular.

These are pretty fully enumerated in the extracts from Reports made to the American Government on wrought-iron guns (Note Z); and refer either to—

1°. Difficulties and uncertainties of manufacture, weldings, &c., common to all large forgings. These we fully admit, and, in what precedes, propose altogether to evade, by another and a better method of construction, which dispenses with large forgings. The special modes of failure and their causes, which many of the largest and most recent cases of proof of heavy wrought-iron guns forged in one piece have presented, are recited in Note AA.

2°. That all that can be gained by the use of wrought-iron for guns is comprised in lightness and strength; that the former is, in fact, not desirable, because, unless the weight is, in field guns, to that of the shot, at least as 140 : 1, and in battering guns as 200 : 1;—the recoil is too great, and is inconvenient. This objection rests

wholly upon the assumption, that there is no other possible mode of absorbing recoil, except by the crude expedient of mass in the gun; and loses sight of the many important advantages which lightness can confer, taken in just connexion with all other relations (Note BB); nor is it an inevitable consequence of increased strength of material, that in every case the weight *shall* be reduced in the inverse proportion.

3°. That a given number of rounds produces a greater enlargement of bore, in the ratio of nearly 2 : 1, than in gun-metal, and hence uncertainty of range, aim, &c. This result, deduced from the utterly insufficient data of one set of experiments with a 6-pounder, is merely a misstatement as to the general fact, as the preceding pages have probably sufficiently proved.

4°. That from want of hardness in wrought-iron, as compared with cast-iron and gun-metal, a seriously objectionable amount of rifling and *ballotage*, or pitting, from the passage of the shot, is to be expected, and, therefore, from this and the following cause, a defect of durability. This also is contrary to all the facts of the case. Wrought-iron is much harder than gun-metal in resisting abrasion, as the fact known to every one, that the gun-metal bearings of axles, such as those of railway carriages, wear much faster than the wrought-iron axle proves; they are for this very reason, made of gun-metal, to save the wear of the axle at their expense. Cavallo's experiments (Nat. Phil. vol. ii. p. 147) also prove this directly. As respects cast-iron, the difference is almost inappreciable between cast-iron best fitted for guns, and wrought-iron, and in favour of the latter in too many instances from the undue softness and friability of the cast-iron employed.

36.—*Particular Conditions of Wear of Guns in Service.*

306. The wear in service of every gun is made up of the rifling out of the whole length of the chase by the passage of the shot, and of the *ballotage*, or pitting, produced by the stroke of the shot, which, for shot of the same caliber

and velocity, will be inversely proportionate to the *hardness* of the material of the gun.

In this respect cast-iron can offer but very slight pretensions, if any, over wrought-iron, while both are immeasurably superior to bronze, and steel to all of them.

307. A third condition of wear, different from either, has been ascertained by careful examination of the heavy guns of the United States Government, known as Columbiads, after sustained firing, and is both novel and interesting.

It was found that a considerable enlargement of bore took place, all upon the upper part of the interior of the chase, just above, and in advance of, the position of the shot, when rammed home.

The greatest enlargement being at about an inch in front of the centre of the shot, and extending as far as three or four inches forward of that point; the surface of the bore here was cut into ridges and furrows, while the opposite side, under the ball, for three or four inches in length, was smoothed and burnished as if the shot had rubbed forcibly over it.

The explanation of this is very instructive. The ball, rammed home, and resting on the lower side of the chase, leaves the whole of the windage open, as a lunaric area, greatest at the upper side, as in diagram, sect. 77. At the moment of explosion, and before the ball's inertia has been overcome, so that it begins to move, as well as during the first instant of its motion, the flame, and perhaps some unignited portions of the powder, are driven out through this lunaric aperture, and past the ball, with enormous force and velocity, both almost reaching the possible maximum, for fired powder. This tremendous blow-pipe, acts upon the interior of the bore at each discharge, precisely in the same way as the issue from the vent, acts in enlarging it, in cast-iron guns, burning away the graphite first, as the most ignitible material, and then burning and blowing away, as oxides and sulphurets, the intervening finely divided fragments of the iron itself.

308. The wear is not uniform, but in ridges and furrows, and for precisely the same reason that the enlargements of the vents, of which numbers have been accurately figured (see "Experiences faités a Gavre, en 1836, sur les Bouches a Feu," &c., Paris, 1837), are all in irregular curved, triangular or multiangular forms.

The first particles of graphite removed, produce a slightly increased area of passage at one place, which results in a greater velocity of the issuing flame and gases at this place of greater area, (on the known principles of Pneuma-dynamics); but the greater velocity here, produces again a greater proportionate wear and abrasion; hence, the moment the cylindrical figure of symmetry, is once lost, the tendency to produce irregularity of section is constantly aggrandized up to a very wide limit, when, at a *very* large section of aperture, the wear all round would again tend to return to uniformity, with a certain constant of surface irregularity, dependent upon the degree of heterogeneity of the material.

This stelliform cutting away of the cast-iron, at the vents of the Columbiads, and other large guns, was found after 300 rounds (8-in. guns) to exceed an inch in diameter from point to point, and after 600 rounds could not be embraced by a circle of two inches diameter. In no single respect, is the minute subdivision of the graphite, and uniformity of texture in the cast-iron for guns, so important as in this, and in none would the superiority of wrought-iron be more manifest.

309. The polish or burnishing of the lower surface of the bore, at the place of the shot, proves that its rotation, by friction against the chase, does not commence instantly upon its first movement, but that it *slides* for a short distance before the frictional grasp of the ball against the bore is able to overcome the inertia of the shot so as to produce rotation; and this also indicates, that at every grazing stroke, afterwards, of the shot against the side of the chase in its progress towards the muzzle, the mutual friction must be that of rubbing or sliding, and not that of rolling surfaces; indeed of rubbing surfaces often, with proper contrary motions, when the ball has acquired previous rotation. So that *ballotage*, is not a wear merely by the grazing stroke of the ball at a very small angle, condensing and pitting the substance of the gun; but an actual abrasion and degradation of its substance, due to rubbing friction at these points of maximum pressure, carried beyond the limits of endurance of the metals.

310. These circumstances throw much light upon the great economy in wear of the chase, produced by the use of the sabots or other solid wads. It is obvious also from the consideration of all the conditions of wear here pointed out, that any conclusions as to material for guns derived from tests of hardness

made by the American methods of trial, viz., by the depth to which a given prism can be forced by a given weight into the material, must lead to entirely fallacious results,—uniformity and chemical relation to combustion being as much elements of wear as hardness.

311. The extent of rifling, or actual scoring away of the metal, at each discharge, for shot of the same caliber and velocity, can only be determined by experiment; but inasmuch as the mechanical part of the reaction is of the same nature as that producing mere friction between surfaces, there cannot be much doubt that the loss of metal at each discharge of cast-iron spherical shot, of equal calibers and velocities, from guns of the same length, but of different materials, will by abrasion only, be some function of the coefficient of friction of cast-iron upon each of these several materials. Now, Morin's experiments, though not embracing exactly what we require, assign the following values for the friction of cast-iron, wrought-iron, and bronze, in terms of the pressure, when in movement on each other:—

Cast-iron on cast-iron, . . .	0·15
Cast-iron on bronze, ...	0·15
Cast-iron on wrought-iron, . .	0·16

The latter is doubtful, as the wrought-iron appears to have been the moving body. We have no corresponding results for steel. These figures, then, would indicate that the loss of material by abrasion only, will not greatly differ in any of these cases.

312. It may appear, that no analogy holds, between friction in which the pressure is kept within the limits of sensible abrasion, and that of scoring out by the rapid shave of a shot in traject; but all friction consists in abrasion, only reduced in degree, and Morin's experiments proved that the resistance to motion produced by it varied directly as the pressure, and was wholly independent of the velocity.

313. It follows, however, that for guns of the same material, and with the same velocity of shot, the wear from this cause, i. e. the weight of metal shaved off at each discharge, will increase with the weight of the shot, or as D^3; while for different velocities it will vary as V^2, upon the accepted principles of *vis viva*. With variable charges of powder, and the same shot, the grooving and enlarge-

ment by combustion and abrasion will be greater as the weight of powder is so, and will be greater for chambered guns with elongated cartridges, which ignite more slowly, and hence give a longer period of issuing flame before the shot moves, than with cylindric bores or quicker igniting powder. The practice with any recorded example of wrought-iron guns has been scarcely sufficient to enable proof as to durability to be drawn from it. We have, however, the following from Major Talcott (Report to the American Minister of War in 1832) upon a wrought-iron 6-pounder, which fired sixty-three rounds with one shot and $1\frac{1}{2}$ lbs. of powder, at Watervleid Arsenal:—

"The iron seems of good quality, tolerably hard for forged iron, and the inequalities of the shot have made very little impression upon the bore,—nothing like the effect that would have been produced upon a brass gun subjected to the same trial."

The wrought-iron 32-pounder made some years since in one solid piece of wrought-iron, under the direction of Captain (now Colonel) Simmons, R.E., is understood to have suffered no perceptible injury in this respect by the practice carried on with it at Shoeburyness. Whatever this objection to wrought-iron may be worth, it has certainly been much overstated.

314. The extent of *ballotage* depends not only upon the material of the gun, and the other conditions above stated, but upon the amount of windage, which, as it is greater, allows more play to the shot in its passage, and lets it strike the sides of the chase alternately at a greater angle. But as wrought-iron guns have the advantage in point of strength, so the windage may be diminished in them with safety, and thus, while this evil may be reduced, greater accuracy of aim, and either longer range or economy of powder, secured.

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315. 5°. That the rapid corrodibility of wrought-iron by air and moisture, and by the residue of the powder, is such, that wrought-iron guns would rapidly become unserviceable, through enlargement of the bore, by mere corrosion. The comparative relations of the four metals has been already made (Chap. 32, Tables XVI.–XVII.) on accurate data, and this objection shown to be perfectly groundless. The degree of corrosion, from any, or all, of these causes, will be quite the same upon a square inch of surface, of the exterior or

interior of a musket or fowling-piece, as upon a wrought-iron cannon; but who ever heard of either having become enlarged or destroyed through inevitable corrosion, under circumstances of ordinary care and cleaning, alike applicable to both?

Examples are given, in Note A, of wrought-iron guns that have been exposed to the weather for centuries, and yet are nearly as serviceable as they ever were.

6°. And lastly, that "wrought-iron guns have been repeatedly attempted to be made, and have never yet succeeded," therefore, they never will succeed; and, in any case, the doubtfulness produced by "previous failures, as to the safety of any such gun, must produce a very bad moral effect on the gunners who serve them."

With what fully equal force might this have been brought forward when cast-iron guns were first proposed, made, and gradually introduced; and at last have superseded all gun-metal guns for garrison, naval, and siege use; although not known, in England at least, prior to the middle of the sixteenth century, and attended with many failures, not only at first, but even to this day; and how entirely does it ignore the vast changes in metallurgic knowledge and manipulative power that have taken place within the last thirty years, as respects iron.

316. *The Special Objections to Wrought-Iron Guns, built up of separate pieces,* —so far as they have occurred to, or have been heard of by, the author—are:—

1°. That the integrant portions of the gun cannot be insured to act together, or with the required concert of resistance, to the explosion, &c. This appears to be disposed of by what precedes; in which it is shown that the very aim and purpose of a gun, built up in the way proposed, is to produce the certainty of greater concert and unity of reaction of all the parts of the gun against the discharge, than is physically possible in guns cast or forged in one solid piece. The dislocations which have been the frequent results of the very first discharge, from many built-up guns within

a short time, presented by their projectors for proof at Woolwich, have arisen in every case from gross ignorance, on the part of their designers, of the first and most obvious dynamic and other principles, upon which the arrangement and proportioning of such must depend.

2°. That the injurious effects of internal local heating, and unequal expansion, must be far more destructive of such guns than of those formed in a single mass. This is exactly the contrary of the conclusion that a just consideration of the properties induced by the construction, in internal compressed and external extended plies, warrants, as will be obvious to the mathematical reader of Note CC and Chaps. 8–14.

3°. That increased, and a highly injurious form of, corrosion may be expected to occur in such guns, penetrating the joints between the adjacent rings, &c., and so forcing them asunder. The simple answer is,—abundant means are at hand, to so far prevent all corrosion, that the objection has no weight; nor has this taken place in the old bombards, to which no care has been given (Note A).

37.—*Resumé and Conclusion.*

317. We have thus pursued the subject to its end—which never contemplated any but incidental treatment, of the practical mechanical operations, necessary to the perfection of ordnance, important as these are, and well deserving of a separate work, of greater compass than has yet appeared; but rather the bringing such light, as the exact and systematic application of physical and mechanical science could throw upon the chief *principles*, on which the true design in form and fabric, and the choice and modes of application of materials for artillery, must rest.

The author, so far as his reading has enabled him to judge, believes this has been now attempted for the first time in a collected form.

318. Many and elaborate experimental researches will yet be requisite before all the data, upon which the art of the gun-founder must rest, shall be

acquired; even some of the most initial, have still to be asked for. Thus, how almost incredible it seems, that in the whole military and civil literature of the world, as bearing on the subject, it cannot be found that the ultimate crushing weight for prisms of gun-metal, the coefficients of its extension and compression in terms of the strain; in fact, not one of its physical data, have as yet been accurately determined. Yet this is the main material with which the artillerists of Europe have been dealing, ever since the dawn of modern science (Note DD).

319. To recapitulate in brief the subjects that have been discussed, and the conclusions, so far as they have been arrived at:—

1°. The molecular structure of cast and of wrought-iron are now for the first time cleared from the confused and perplexed state in which our knowledge remained, and brought under a single crystallographic law; which, like every truth, when once grasped, not only becomes a light to clear up the darkness and confusion behind, but enables us to predict the results of combinations and circumstances yet to arise.

2°. The application of this law to cast-iron in cannon has shown the nature, causes, and positions of "planes of weakness;" their results in producing fracture, and the modes of their avoidance.

3°. The application of the law to wrought-iron has shown the true relations of the mass, and mode of formation, to the strength, elasticity, and other properties of wrought-iron guns.

4°. The effects produced by mere changes of mass, all other conditions being the same, have been shown both for cast and wrought-iron.

5°. The physical conditions of moulding and casting guns, in cast-iron (irrespective of any questions of mere manipulation or of practical detail) have been in a determinate manner discussed, their principles endeavoured to be fixed, and the relations of temperature, molten pressure of head, rate of cooling, &c., indicated.

6°. The relations as to "fitness of make" and quality of cast-iron for gun-founding, of British and foreign cast-irons have been compared; mistakes as to the supposed superior and inimitable value, of the latter corrected; and the principles pointed out upon which British cast-iron suited to gun-founding may be readily obtained.

7°. The relations also of British and foreign wrought-iron have been pointed out, and some popular notions of the invariable superiority of the latter brought into question.

8°. The principles upon which depends success in future efforts to procure large masses of wrought-iron, of reliable quality, have been deduced from the principles ascertained as to its molecular constitution, as determined by the mode of manufacture.

9°. The difficulties affecting the applications of gun-metal have been treated with more regard to chemical and physical science than appears to have been previously done, and some suggestions offered as to directions of probable improvement in the methods of alloying and moulding the metal; with explanations not before given, of some of the singular and obscure phenomena of its consolidation. The most elaborate previous treatises on this subject, such as those of Massas, Meyer, and Hervé, left very much to be desired, and much remains yet to be investigated.

10°. The general comparison of physical, and other properties, of the four great materials for ordnance has been finally reduced to tabulation, and their fiscal relations compared.

11°. The important relations of elasticity and extensibility, to ultimate strength, in guns of whatever material, have been discussed, and the result pointed out,—that mere tenacity is not a sufficient guide; that the safe coefficient of rupture, cannot be taken at more than one half that safe for static loads, since the extension for impulse is double that for passive strain.

12°. The important relations of elasticity to crystalline axis in wrought-iron, developed by the application of the general law of its crystallization, has been made the basis, in connexion with the theoretic conditions of resistance to internal pressure, for proposing a better combination of wrought-iron in guns; in principle, radically different from anything previously brought forward.

13°. The prevalent notions, as to the vast superiority of steel as a material for ordnance, have been, it is hoped, assigned their just value.

14°. The nature and effects of distortion by unequal temperature, in

guns have been pointed out, and the conditions of their injury or destruction thereby shown; the precautions necessary in firing red-hot shot, &c., indicated; some ancient mistakes rectified; and the comparative values of the four great materials for ordnance, in respect to distortion, ascertained.

15°. The long-vexed and confused question, as to the presumed deterioration of wrought-iron at common temperatures by vibration, has been cleared up, in a great degree, by the application to it of the general law of crystallization; the causes of the changes of fracture, under the stroke of shot, pointed out for the first time; with a comparison of the effects of the stroke of shot upon the four great materials of ordnance.

16°. The relations of the rapidity of the exploding agent to the material of the gun have been discussed, and some more precise views advanced of the nature and conditions of wear, and enlargement of vent and bore in guns.

17°. The effects of position, with respect to the axis of the gun, upon the ultimate resistance of the metallic filament, has been investigated in a new light, and its relations to,—

18°. The effects, on the resistance of the gun, of the position of its trunnions, or other fulcra of recoil, and of the simultaneous action of forces of extension and compression within its mass.

19°. The doctrines of authors on Physics, as to the relations between the force of contraction or expansion by heat, and corresponding mechanical effect in metals, has been placed in a new light, and, it is hoped, with some advance of truth.

20°. Some new views as to the nature and effects of annealing, and the relations between the temperature at which it takes place, and that of fusion, and of the work done by rupture, on hard or unannealed and on soft or annealed metals, have been adduced.

21°. The relative advantages, and the objections which may be urged against the adoption of wrought-iron guns, and especially of that peculiar construction proposed, have been discussed, it is hoped, in a true and impartial spirit.

320. If universal civil engineering experience has, after the most careful inquiry abandoned the use of cast-iron wherever impulsive and tensile forces are together concerned in structures or machines, and substituted wrought-iron, it is difficult to discover any reason why the same should not be done in the construction of artillery; which is in itself essentially a work of civil or mechanical engineering; admittedly so, according to some of the ablest military authors. "De este modo la Artilleria es sencillamente una aplicacion immediata de la mechánica, contraida al estudio de una especie particular de máquinas" (Senderos, Elem. de Artil.)

The advocacy of this, the attempt to facilitate and perfect it, have been, in part, the aim of what precedes.

In the attempt, whether successful or not, the author can truly say, in the words of Bacon, that he has endeavoured to lay his mind unbiassed to the question, "so that, like a pure mirror, it should reflect nature without distortion." He had no preconceived views: and as all the main inquiry of the work had been completed long before he became acquainted with the somewhat meagre literature of the subject abroad,—there is none, he regrets to say, at home, (Note EE),—and wholly independently: so he neither copied the notions, nor was prejudiced by the preconceived views, of others.

Note A.—(Sect. 1.)

Discovery of Gunpowder and Cannon.

At the first thought it seems strange that some of the most remarkable discoveries, and which have had the greatest influence upon the progress and destinies of mankind, are amongst those of which the least is known concerning their authors. Such is the case with respect to gunpowder and artillery, which, next to printing and steam power, have had perhaps the greatest material effects upon man's condition and progress.

This very obscurity is, however, a proof of the antiquity of the knowledge, and is common to almost all the great and important discoveries by means of which our daily wants are supplied. Who can tell when leavened bread was first baked?—where animal power was first made to aid man in subduing the earth by the plough?—where woven fabrics, and twisted cordage that preceded them,—where the use of calcareous cements in building,—were discovered; still less, to whom individually these great improvements were due? Nor was the early want of printed books or records the cause of this uncertainty, as the history of invention in our own day proves, where it often happens that a discovery essentially of the highest interest or importance is not recognised at once, and yet, after a time, when these are seen, it is found impossible to award the palm of discovery to any individual.

The electrotype and daguerrotype are examples known to all; and this, apart from that wide class of human advances which have formed the base of so much controversy in modern times, such as, who was the inventor of steam navigation, or as will, doubtless, be hereafter asked, who invented the locomotive?—the true answer to which is, no one. These are the conjoint results, the coalesced product of the separate inventions of innumerable minds. Indeed, the history of human invention presents little that can be attributed with absolute certainty to individuals, beyond the salient discoveries of exact science, and of a late period. Perhaps even this ground is not without dispute, as Newton and Leibnitz may witness.

It is with rather a narrow appreciation of the subject, as well as in neglect of much historical information, that, with most authors, either Bacon or Schwartz has been assumed as the inventor of gunpowder. Another class of archæologists admit the knowledge of gunpowder to have been of extreme antiquity in the East, but at once grant the honour of separate, though subsequent, original discovery to the European monks. Yet the ground for this seems to be no more than that, in their writings, the earliest recorded mention of the great discovery is made in any European language. Roger Bacon, unquestionably antecedent to his German rival, was born 1214, and died 1292; and his work, "De Nullitate Magiæ," appears to have been written about 1270, while Kircher's account gives 1354, or the date of the discovery by Schwartz.

It appears, however, that an Arabic manuscript exists in the collection of the Escurial, which unmistakably describes gunpowder and its properties, the date of which is anterior to 1250. (Caseri, "Bib. Arab. Hispan." t. xi. p. 7.)

The opinions of Spanish authors may be given in the words of Senderos (Elem. de Artil.):—"Es muy probable que la pólvera se haya conocido por varios pueblos del Asia, desde una grande antigüedad, pero su invencion en Europa se atribuye generalmente al quimico Inglés Rogerio Bacon á principios del siglo XIII."

The impression given by Bacon's account is not that of a man divulging a most surprising and new discovery of his own, but of one referring to a discovery already made by others, and known to him, though not, indeed, commonly known; and it is remarkable that all the earliest noticers of gunpowder and of artillery throughout Europe speak as of something already known, and more or less in use here or there. The most probable case seems to be, that both Bacon and Schwartz (the former clearly the earlier) were but the learned divulgers of information derived from elsewhere.

In attempting to trace back invention or discovery, we shall often obtain a broader light (through the gloom of past ages) by endeavouring to refer the discovery and the records of it into collation with the material conditions and substances upon which it depended, as well as with the knowledge, manners, laws, polity, and traditions of the period.

Nitre, produced so sparingly in temperate climates as to excite scarcely any observation, and to be with difficulty collected, has ever been the spontaneous production of India and China, in such abundance as to challenge mankind to its examination and trial. Sulphur (גָּפְרִית), and coal, i. e. charcoal (פֶּחָם), are known and mentioned by their properties at the early periods of Moses and the Book of Job.* The former, found abundantly in China and throughout the volcanic regions of Syria, of Lake Baikal, and central Asia; the latter, the necessary product of the extinction of the first fire of wood fuel—that which was (unless we except naphtha and bitumen) the sole fuel of the East. That some explosive compound of these widely scattered native products should have been early hit upon in these dry and warm climes, and that the first observation of the phenomena should so powerfully arrest the attention of races whose imaginations have ever leaned towards the mystical and marvellous, seem almost inevitable; and equally so, that all this may most probably have occurred at a very early epoch of the world's history. The earliest recorded notices, however (perhaps Oriental scholars may know of others much anterior), seem to be those of Philostratus, Themistius, and others, in relation to Alexander's campaigns in Asia, of some terrible missile, simulating thunder and lightning, in the hands of the Oriental sages, the irresistible power of which stopped the conqueror at the Hyphasis; and all of which is condensed into a few lines by Lord Bacon in his Essay "On the Vicissitude of Things," who thought

* See Note, page 339.

it "certain that ordnance was known in the city of the Oxydraces in India, in Alexander's time." Many circumstances, however, seem to point to the use of cannon in China at a far earlier period than that of Alexander (B.C. 300) ("Etudes sur le passé et l'avenir de l'Artillerie," par le Prince Louis Napoleon, t. i.—Colonel Chesney, "Observations on the Past and Present State of Firearms," &c., vol. i.)

For centuries the East and the West were separated as by an impassable gulf. Asia knew nothing of Europe; Europe but touched the coasts and confines of the great Eastern continents. The annual expeditions of Solomon, coasting the further Arabia, reached probably at farthest but to the southern coasts of Persia or the mouths of the Indus. The Indian trade of Rome, so slender that the paucity of supply made a pound of silk worth a pound of gold there, was carried on through Egypt and the Red Sea, but seems to have reached no further than the Malabar coast and to Ceylon, and to have mainly consisted in silk, pearls, gems, spices, and gums (Gibbon, "Decline and Fall"). The invasion of Alexander, the voyage of Nearchus, were but exceptional cases; and the unusual appearance of strangers from the East, even at the commencement of our era, is indicated by the account given of the worship of the Magi at Bethlehem. But with Christianity began the great breaking up of ancient systems, and the vast military and social migrations and new localizations of mankind. Through Egypt and Asia Minor some of the obscure and half occult knowledge of alchemy, of magic, and "curious arts," which the severer science of Greece, and the splendid power of imperial Rome, had despised, had at length travelled westward; yet not unopposed, for in A.D. 290, Diocletian burns, by edict, all the alchemistic books in Egypt. The invader's sword, however, was soon to dislocate everything; from the meridians eastward of Scythia, as from a dividing line, Tartars and Moguls poured into India; the northern nations precipitated themselves upon the Roman Empire and upon southern Europe; ere long the conquering Arabs appear upon the disturbed European scene; and before the end of the seventh century their vast empire extends from Bagdad to Granada and Morocco. Soldiers and nomads at first, they yet brought with them some of the arts and science, the poetry and literature, the refined and luxurious tastes, of the ancient East, which, under the firm dynasty of the Abbassides, received those later developments which our own paper, sugar, and Arabic numerals attest. The fanatic element of power is now added; from the cloudy dust of the desert the whirlwind of Mahomet's cavalry emerges, beneath which in later day the Eastern Empire is overthrown, and which at last is only with difficulty stayed beneath the walls of Vienna.

It may be asked, then, how is it that the warlike race of Islam, coming from the land of this wondrous secret, which was known also to the learned amongst themselves, never used it as a weapon of warfare until the eleventh century, when the Moors in Spain seem to have applied gunpowder in sieges? (Sismondi, "Hist. Literat." by Roscoe, vol. I. cap. ii.) The answer seems to be, they were mounted, a nation of cavalry; the sword, pronounced by Mahomet himself "the key of heaven and of hell," was their favourite and most effec-

tive weapon ; and, as with the Roman legions, the sword and "pilum" bore the brunt of battle,—missile arms being resigned disdainfully to the "velites,"—so might the words in which the great Roman historian always describes the crisis of the fight, be applied to every Moslem victory—"Gladiis res geritur." It was not until the tide of victory brought their successors in front of the walled cities of the West, that the need of gunpowder was found.

Reverting again to Europe, between the fifth and the twelfth century, "old things had passed away ;" Christianity had established herself upon the ruin of the ancient creeds. "The sword," which, its Author had predicted it, should bring with it invasion and bloodshed, had given place to something like the stability of governments; and the distinctions of new-born languages and kingdoms, the germs of our modern civilization, were developed. "Society already possessed kings, a lay aristocracy, clergy, burghers, labourers, and civil powers." (Guizot, "Hist. de la Civil." t. I. lect. viii.) Trades had been developed, and their mysteries were in the hands of the craftsmen and free burghers of the trading cities. Travelling on distant expeditions was rare, except for the purposes of merchandize or pilgrimage to the holy shrines. Churchmen and monks became thus those best acquainted with foreign lands, and often were intrusted with diplomatic missions, as distant as even to the Great Khan. (Abel Remusat, "Mem. sur les Relations Politique," &c. 2me Mem. pp. 154–157.) Thus, Ascelin and J. de Plano Carpini, travelling friars, were sent as ambassadors by Pope Innocent IV. into the heart of Asia, just at the end of the twelfth century. (Murray, "Hist. Discov. in Asia.") Whatever learning, whatever science remained unburied, were also possessed by them. Would it not have been wonderful, then, if they were not the best informed men of their times as to all that was of foreign occurrence—if they had not been the introducers of much that was new, strange, and valuable, from the distant and ancient lands that they visited? They were so, as the introduction of many exotic plants attests, which, spreading from the monastery gardens of Europe, as from centres, have long become naturalized over wide habitats, as our possession of the treasures of ancient learning, rescued from the wreck of the East, and preserved in their libraries, proves.

They returned with imaginations heated, and intellects fired and energized, by their transit from the learned leisure, or perhaps the sloth and sensuality of their cells, to the glorious scenes and monuments of ancient story, and the richness of southern climes. The preaching of one such man set Europe again in a blaze: at the voice of Peter the Hermit, all Christendom prepared to throw itself upon the East, as Islamism had before rushed upon the West. From the eleventh to the end of the thirteenth century, Crusade after Crusade made these ancient but now decaying lands more and more familiar to the churchmen and to the chivalry of the Cross.

The former, however, were alone fitted either to collect and treasure, or to transmit by

writings, the lore, the knowledge of the productions, the arts and sciences, of the lands and peoples amongst whom they travelled. They carried back these acquisitions to their own monasteries, and they communicated them to their clerkly brethren, as they made their rounds of visits, from religious house to house; and thus it was, that from the seclusion and silence of the cloister and the cell were echoed, in the furthest North and West, the inventions, the arts, the discoveries, of distant lands and foreign people; the announcement of which—as in the instances of Bacon and of Schwartz, with gunpowder—bear to us now at first the impressions of original discovery made by the men themselves, as if buried in the solitude of study, which were, in fact, most often but gathered from those of their itinerant brethren who were then the great news-venders of the world. The conclusion, therefore, seems justifiable, that gunpowder, known from a remote antiquity in eastern and southern Asia, was not independently re-invented or discovered in Europe; but that the knowledge of it travelled westward with the Arabians, and with the returning bands of pilgrims and crusaders from Syria and Palestine; and was introduced into the Levant and Spain by the former, and into Scotland, England, and Germany, by the latter.

But we must be brief; it is impossible, within the limits of a Note, even to sketch this history perfectly, for to do so of any one discovery, is in many respects to write the history of all human progress. Yet, much as has been penned by various authors on the subject, we make bold to say, the real history of the discovery of gunpowder and of cannon, or firearms generally, remains still to be written, and, whenever attempted with success, it will be by him who shall be competent to unfold the lore laid up in Arabic MSS. in the monasteries and palaces of Spain and of the East, and who shall endeavour to collect and to collate the still extant records of the burgher cities of southern and central Europe, and such other fiscal or state documents as may best develop the sources and channels through which Europe was supplied with saltpetre and sulphur at the earliest periods, say from the eleventh century. To these, rather than to the learned dust of alchemy, are we to look for future information.

The *Saltpetre regale*, by which, under a sort of royal patent, the right of searching for and collecting incrustations of this salt, even from the walls of private dwellings, existed amongst, and was hated by, the people of Germany, does not seem to have been known anterior to the fifteenth century, if so early. Artillery, however, was common all over Europe in the middle of the fourteenth century, and the total production of the *regale* could not have supplied a tithe of the demand. Whence, then, was the supply?

If gunpowder itself be admitted to have been known for an immense period in the east of Asia, it is not conceivable that some forms of firearms, and cannon as the very simplest, must not have been known there likewise. The corollary is too obvious and simple, long to escape even a very barbarous people.

From the early date of the notices already referred to, which make it so probable that

Alexander was opposed by artillery, down to the end of the twelfth or beginning of the thirteenth century, no records of its use in Asia appear known in European tongues; such may exist in Oriental languages, however.

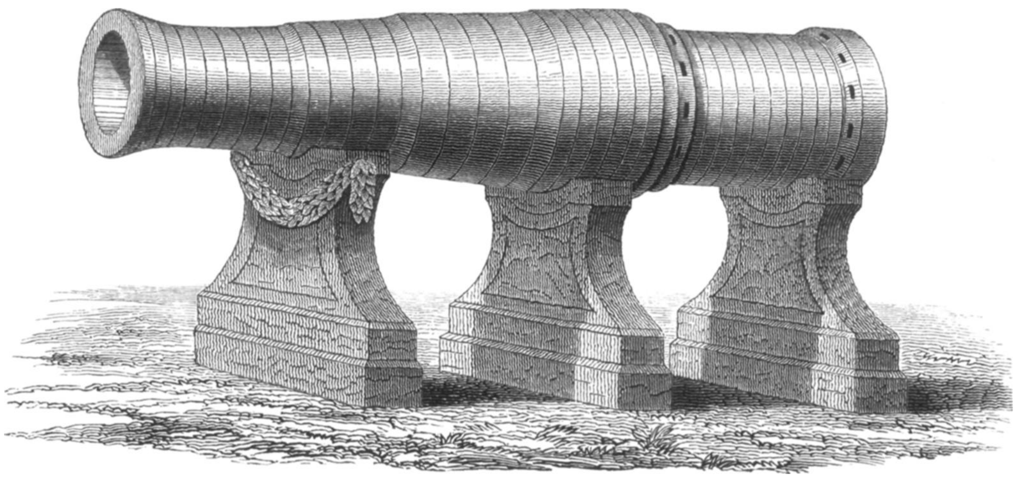
Carpini, writing in 1246, says, that he observed that the armies of Prester John had copper tubes, which, mounted on horseback, vomited, in a wonderful manner (he knew not how), fire and smoke, whereby his enemies were struck and overthrown (Murray, "Hist. Disc."). These seem to have been the predecessors of the Camel batteries, so common in the East at this day.

It is impossible, however, here to refer to innumerable facts, scattered through many authors, that sustain this view, and indicate not only that cannon were made and in use in China and the Indian peninsula at a very remote period, and, with the knowledge of gunpowder, conveyed thence into Europe, but that even the early methods of manufacture were brought also from the East. As to the former, amongst many others, the following works may be consulted:—Murray's "Hist. Discoveries in Asia;" Staunton's "Embassy to China;" Du Halde's "History of China;" Elliott's "Bibliogr. Index, Hist. Moham. India;" Favé, "Des Origines de la Poudre;" La Lanne, "Acad. des Inscrip., 1840; Brigg's "Hist. Moham. Power in India;" "Algemeine Deutsche Encycl.;" "Marion recueil des bouches a Feu les plus remark," &c.; Col. Symes' "Embassy to Ava;" and the works previously quoted. The latter proposition, as to the early knowledge of fire-arms in Asia, will become illustrated by the following—

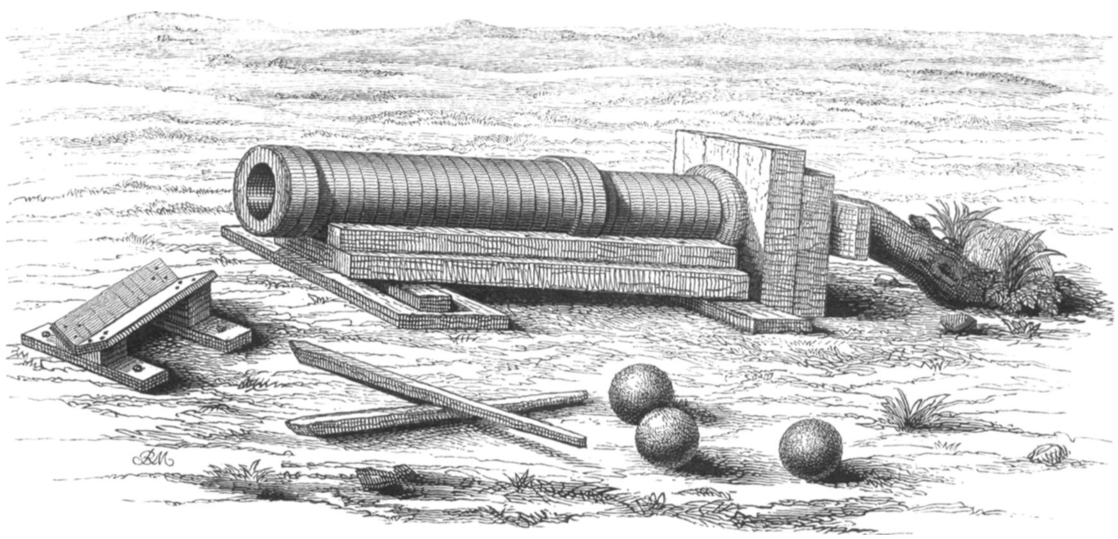
Notices of some of the most remarkable Ancient Cannon, in Size or Construction.

The earliest European artillery of large size consisted of "Serpentines" and "Bombards,"—both being formed of longitudinal bars of wrought-iron, arranged like the staves of a cask, and hooped all over, or nearly so, with wrought-iron rings, shrunk-on hot upon the bars. The Serpentine was of small caliber, but of enormous length. Perhaps the most remarkable specimen existing is in the collection of the Arsenal of Neuville, canton of Berne: it is only about 2 inches caliber, but about 10 feet in length of chase, or about sixty calibers, formed of wrought-iron, with rings shrunk-on at some inches apart; the breech is fixed, and it was loaded from the muzzle. The gun lies imbedded to its horizontal diameter, and for its whole length, in a timber bed, like a musket-stock, against which the breech abuts, as it has no trunnions. The whole is mounted on a well-contrived field carriage, with two large wheels and trail; the bed or stock of the gun being balanced over the axle and jointed to the trail, so as to elevate and depress in a very judicious manner. The whole is extremely interesting, as presenting the germ of our modern field artillery-carriage. The total weight is nearly 4 tons. It was taken by the Swiss, from Charles le Temeraire, at the battle of Granson, in 1476, and an engraving of it occurs in the Emperor

PLATE VII.



Great Bombard of Ghent.



Bombard on Bed.

Napoleon's work, "Passé et l'avenir d'Artillerie." Charles is said to have possessed pieces of 7, 10, 20, and 30 livres' weight of ball (probably of lead) upon this construction, which was well fitted to give a large range with the slow-burning powder then in use, before the invention of granulation.

The bombard was usually a much shorter piece, often of immense caliber, but formed of wrought-iron much in the same way, except that the inner bars were separate longitudinal ones, in place of an united cylinder, the external rings being common to both; it was, in fact, an immense howitzer, the chase being generally in length from five to eight calibers, and used for throwing stone balls. The chamber, also of wrought-iron, was at first separate from the chase, socketed into and secured to the latter by rings and lashings; but in later examples the chamber and chase are united into one mass. The former construction is that of the great bombard recovered from the bed of the Bahgretti, at Moorshedabad, in Bengal; the latter, that of the Mons Meg, of Edinburgh Castle, and of the great bombard of Ghent, all about to be described. In either case, the only carriage used for the gun was a long trough-like sleeper of timber, often of the rude construction shown in the annexed figure; the change of elevation being produced by blocking up in front; and the stone shot being rolled into the muzzle, up a sort of movable inclined trough of wood, by handspikes. The whole recoil was borne by a firm blocking of timber fixed in rere of the breech, between which and the blocking a stuffed pad of leather seems to have been sometimes interposed as a buffer.

The velocity of recoil was not great, and the mass of the chamber-piece was considerable, so that, when made separately, the tendency of the latter, and of the chase, to part off from each other at the moment of recoil was not very great with this mode of mounting. In smaller and longer pieces of wrought-iron of this early period, as in those recovered from the "Mary Rose," wrecked in 1545, one of which has a caliber of about 6½ inches, and a length of about 8 feet, though formed and mounted much in the same way, the chamber-piece is either in one solid piece with the chase, or separate and movable chambers were dropped in between jaws projecting backwards and in one piece with the chase, and were there secured by a coin wedge behind, in precisely the same manner as the Oriental gingals. It will be thus already remarked, that the construction of these largest and earliest cannon is identical in Europe and in India and China. It will be better, however, to reserve further observations until we have described a few of the most striking examples.

Great Gun of Ghent, or Gand.—In various works the great cannon of Ghent is mentioned, as, — Dierickx, "Memoires sur la Ville de Gand," vol. ii., p. 144; P. Senz, "Nouvelles Archives Historiques, Philosophiques, et Littéraires," vol. ii., p. 607; Voisin, "Guide des Voyageurs dans la Ville de Gand," p. 300; F. De Vigne, "Sur l'Usage des Armes à Feu; le Messager des Sciences et des Arts:" a collection published by the Society of Fine Arts and Letters at Ghent, vol. v., pp. 101, 128.

The following is from Voisin:—" This enormous cannon, or ancient bombard, is one of the most curious pieces of artillery known, both in dimensions and construction, which is a *chef d'œuvre* of the art of forging. It is 18 feet in length, by 10 feet 6 inches in circumference; the mouth is $2\frac{3}{4}$ feet in diameter; it is forged from bars of iron, and weighs 33,606 lbs., and threw a stone ball of 600 lbs. weight. Its construction appears to date from the early years of the invention of artillery; in all probability it was forged while Philippe Van Artevelde, Riswaert of Flanders, was besieging Oudenarde, in 1382.

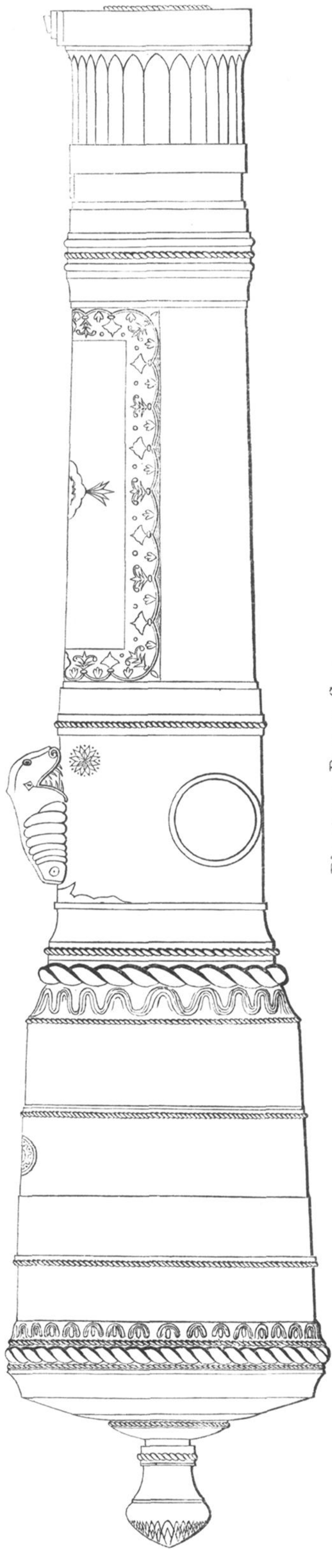
" It is certain that the people of Ghent, at war with their Duke Philippe, used it in 1411, and at the attack of Oudenarde, in 1452; and that, forced to abandon the siege, their great piece of artillery, which they were not able to drag along with them, fell into the hands of the burghers of that city, commanded by Gaspard Van der Moiren. It is probable that they of Oudenarde, who took part with the Duke of Burgundy, caused the arms of that prince to be engraved upon it.

" During the great revolt against the Spaniards, this famous piece, which Oudenarde had preserved for nearly a century as a civic trophy, was recaptured by the Gantois leader, Rockelfing, transported to Ghent by the Escaut, and discharged on the 8th March, 1578, from the quay Kuypyat, now the plain Des Recollets. It was placed, the same year,—at Mannekins-aerd, near the Marché du Vendredi, where it is still to be seen,—upon wooden trestles, which were several times renewed. These trestles were replaced, about 1783, by the three freestone pedestals, which are represented, and on which it now stands.

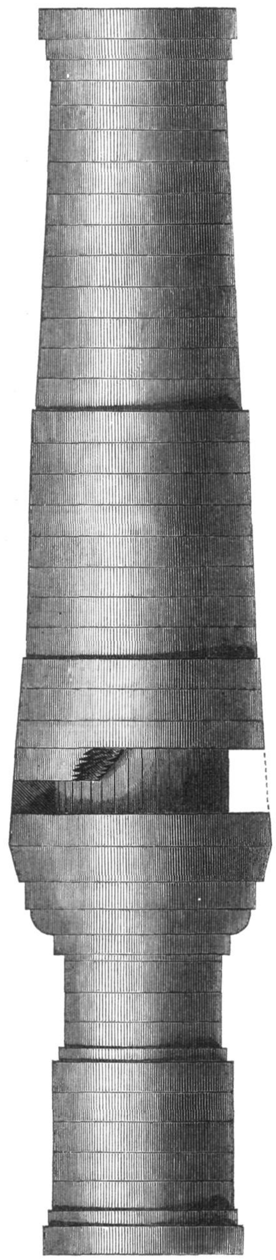
" It served for throwing stone balls, or barrels containing a kind of grape-shot, composed of pieces of stone, iron, or glass, &c. The chamber is made separate from the chase, but is reunited to it in the same manner as in some of the bronze pieces which defend the entrance of the Dardanelles: these have nearly the same form and dimensions as the bombard of Ghent, which is believed to be the largest in Europe. The cannon which draws the attention of strangers in the Arsenal at St. Petersburg is 21 feet long, but it only weighs 17,435 lbs., and its caliber is only 68 lbs.

" The great cannon of Ghent still bears the sobriquet of Dulle Griette (the Raging Meg), whether in allusion to the noise which it made by its report, or to perpetuate the evil fame of Margaret, Countess of Flanders, who died in 1279. The hatred which this princess bore all her life to the children of her first marriage, Jean et Baudoin d'Avesnes, caused the greatest misfortunes in Flanders, and she bore to the grave the name of the Black Lady, which the people had given her. Some of the French chroniclers say the piece was commonly called " Margot la Folle."

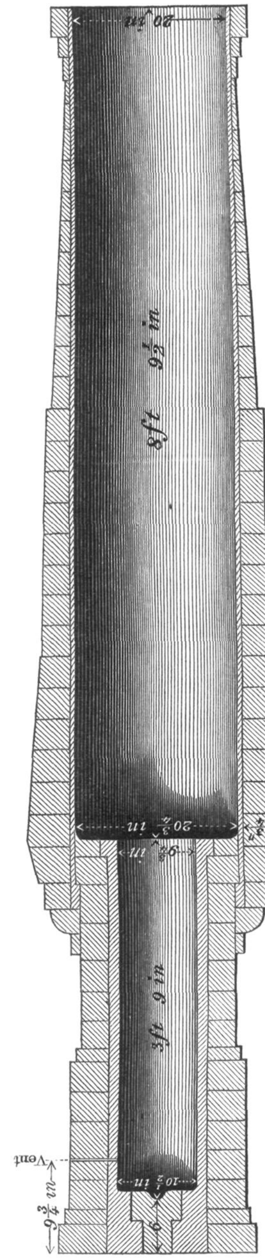
PLATE VIII.



Bhurtpore Bronze Gun.



Mons Meg, Edinburgh Castle—External Elevation.



Mons Meg, Edinburgh Castle—Longitudinal Section.

"The following are its exact dimensions:—

	French Metres.		English Inches.
Length of the chamber, outside,	1·53	=	60·237
Length of the chamber, inside,	1·30	=	51·182
Average diameter of the exterior of the chamber,	0·73	=	28·741
Average internal diameter of the chamber,	0·25	=	9·843
Average thickness of the wall of the chamber,	0·24	=	9·449
Length of the chase, outside,	3·49	=	137·404
Interior length of the chase,	3·23	=	127·168
Average exterior diameter of the chase,	0·90	=	35·434
Interior diameter of the chase,	0·65	=	25·591
Average thickness of the wall of the chase,	0·12	=	4·724
Thickness of the longitudinal bars of the chase at the mouth of the cannon,	0·45	=	1·772
Thickness of the exterior rings, varying from 0·08 metres = 3·150 inches, to	0·04	=	1·575"

The Gantois are alleged to have possessed a serpentine at the siege of Oudenarde, in 1382, of *fifty feet* in length.

I am indebted for the preceding dimensions to the favour of Mons. Quetelet, of Bruxelles, and of Professor Duprez, of Gand.

The Mons Meg of Scotland.—Through the kindness of Colonel Moody, R. E., I am indebted to Captain R. Grant, R. E., of the Commanding Royal Engineers' Staff, Edinburgh, for the following particulars as to Mons Meg,—perhaps the next ancient bombard, in size and interest, in Europe, which, after many changes of place and fortune, now rests as a trophy in the King's Bastion, Edinburgh Castle:—

Formed of longitudinal stave bars, in one ply only, and of superimposed rings, driven and shrunk-on upon the taper, in one ply also, the general construction of this gun is similar to that of Gand, and may be distinctly understood from the section above. The mode of connexion between the longitudinal bars of the chase and of the chamber cannot now be clearly ascertained, being covered by the exterior rings, and from the effects of corrosion; that which is drawn above, therefore, is so far inferential. There seems ground for believing that, in some instances, the chamber-pieces were fixed to the chase by the interlacing of a rude set of ring notches in the overlapping ends of the longitudinal bars, and, according to Piobert, they were sometimes screwed together. The chamber-piece Captain Grant considers to be formed of rings welded into one piece; but this is improbable, considering the limited forging capabilities of the age in which it was made. The joints of the rings were very well fitted at this important part; and ancient rust, converted by time into crystalline hematite, as hard as the iron itself, has so filled the interstices as

to make it appear one mass. The longitudinal bars are parallel in thickness throughout, and meet edge to edge, but their exterior and interior are slightly taper; the chase, therefore, is not cylindrical, but conical, as is also the chamber; the caliber at the muzzle being 20 inches, and that at the bottom, close to the chamber, 20¾ inches. The effect of this was to give a much larger windage at the commencement of motion of the stone ball than at its leaving the piece, which, with very slow-burning powder, must have greatly eased the strain upon the gun, without very materially reducing the velocity and range.

This advantage *may* have been intentional; but the primary object of this taper was, no doubt, to facilitate the getting on of the external rings when red hot. It is obviously so formed by design, and not by accident or error of workmanship; and, being a uniform taper, could not have resulted from swelling produced by the strain of explosion acting most severely towards the breech.

The following are the principal dimensions:—

	Feet.	Inches.
Total length,	13	6
External diameter of muzzle,	0	24¾
External diameter of breech,	0	27
Greatest external diameter,	2	4¾
Length of chase, interior,	8	9½
Caliber at muzzle,	0	20
Caliber at breech,	0	20¾
Longitudinal bars, twenty-five, each ¾ in. thick × 2½ in. nearly.		
External rings, average width, 3¼ ins. ,, ,,		
,, ,, radial thickness, from 3¾ in. to ½ in.		
Length of chamber, interior,	3	9
Diameter at mouth,	0	9¾
Diameter at breech,	0	10½
Thickness of wall of chamber, minimum,	0	6
Thickness of breech in line of axis,	0	5¾
Vent, distant from exterior of breech in line of axis,	0	9¼

The vent is much enlarged (though still round), owing to corrosion.

The iron of the gun has been commonly supposed Swedish; it is much more probable, however, that it is of iron faggoted up by hand-hammers from small bars of native-made charcoal-iron, from the ancient forges of Cumberland or other parts of the Border country. Iron thus wrought is perfectly undistinguishable from Swedish, though usually a little softer.

The following is the history and tradition respecting this gun, taken from "The Statistical Account of Scotland:"—

"When the Act of Forfeiture against the Douglas was passed by the Scottish Parliament, in 1455, and the castle of Threave was the last stronghold of that family, King James II. marched into Galloway, and taking up a position near where the town of Castle Douglas now stands, besieged it. Amongst the country-people who came to witness the siege were a blacksmith and his sons, named M'Kin, or M'Kew. Seeing that the royal artillery produced no effect, old M'Kin offered, if furnished with proper materials, to make a more efficient piece of ordnance. The King gladly accepted the proposal, and the people of Kirkcudbright each contributed a bar of iron, out of which M'Kin produced the gun called Mons Meg. It was made at Buchan's Croft, close to the 'Three Thorns of Carlin Wark,' where the King had encamped. Its weight was 6½ tons, and its caliber 19½ inches; the charge of powder was a peck; and in a short time the garrison surrendered. The king gave M'Kin the forfeited lands of Mollance as a reward: M'Kin soon became called (as was the custom) Mollance, after his lands. The cannon was named after him, with the addition of Meg, his wife's name, whose voice was said to rival that of her namesake. Thus the original name of the gun, Mollance Meg, was soon shortened into Mons Meg."

All this may possibly be true, but it looks most improbable, so far as the name is concerned; it is but a sample of that loose sort of vapid fable with a circumstance, with which antiquaries are apt to be satisfied. It will have been remarked that the Gantois gun is a Meg, too, as are many other large guns popularly throughout Germany. The truth seems to be—"Grete," "Gretchen," is familiarly applied by the vulgar, in Germany and Flanders, to any huge machine that does "virago" work, just as "Jenny" is with us applied to any one that performs drudgery, as in "spinning-jenny," or, as the old Scottish guillotine was called, "The Maiden," and the "Mons" was probably nothing more than an abbreviation of monster. The whole tale, moreover, is rendered improbable by the statement of Pennant ("Northern Tour"), who says that *the sister gun to Mons Meg* proved fatal to James II. of Scotland, by bursting near his person. This was at the siege of Roxburgh Castle, which had remained in the hands of an English garrison from the time of the Battle of Durham, in 1460.

However, it is quite possible the iron was forged and the gun made in Scotland by M'Kin, and that he was a craftsman of some of the blacksmiths' guilds in Scottish burghs; but the design of the gun came from the Continent,—at least is identical with that previously adopted in various parts of Europe and in Asia, from a remote antiquity. The ancient and celebrated fabricators of cutting weapons in Scotland, it will be recollected, were not natives, but foreign artisans from the north of Italy and from Spain.

Mons Meg was used at the siege of Dumbarton, in 1489; was then brought back to Edinburgh, and reposed there for eight years; was next brought to Norham, in 1497; was afterwards used to fire a salute, in 1548, when Queen Mary married the Dauphin of France; and in 1682, when firing a salute in honour of the Duke of York, the iron rings, which are now partly wanting near the breech, were blown away, though without much disturbing

the longitudinal bars,—probably the effects of the more rapidly igniting powder then becoming known. The gun actually discharged balls of Galloway granite against Threave Castle. The weight of a granite ball of $19\frac{1}{2}$ inches diameter is about 330 lbs. When the extreme thinness of the gun towards the muzzle—indeed its general thinness—is considered, we cannot avoid being impressed with the real skill shown in the construction of these built-up guns, in which, despite the difficulties which the infant state of metallurgic art interposed, and unaided by science, with nothing but mother wit and patient "trial and error" to guide them, these ancient craftsmen arrived at a construction which the science of to-day affirms within one stage of being theoretically perfect, and succeeded practically in producing weapons which in magnitude are only now about to be surpassed. Nor, when we call to mind the state of fortification from the thirteenth to the beginning of the sixteenth centuries, are we less struck with the extreme suitability of these bombards to the work they were called on to perform. The strongholds were all of masonry: earthworks and bastions were not developed before the fifteenth century. Large and heavy shot, thrown with moderate velocity, was precisely that which in the then state of the arts, and of warfare, gave the most efficient breaching power. The latest and most formidable fortifications in Europe have returned to masonry in casemates to a vast extent; our floating batteries of attack are become shot-proof: we shall yet return to the bombard, though improved and empowered.

The third and last bombard which I purpose noticing, is that which was dug out of the bed of the Bhagretti river a few years since, by Mr. H. Torrens, Political Agent at the Court of the Nabob Nazim of Bengal, and which now stands opposite the palace at Moorshedabad.

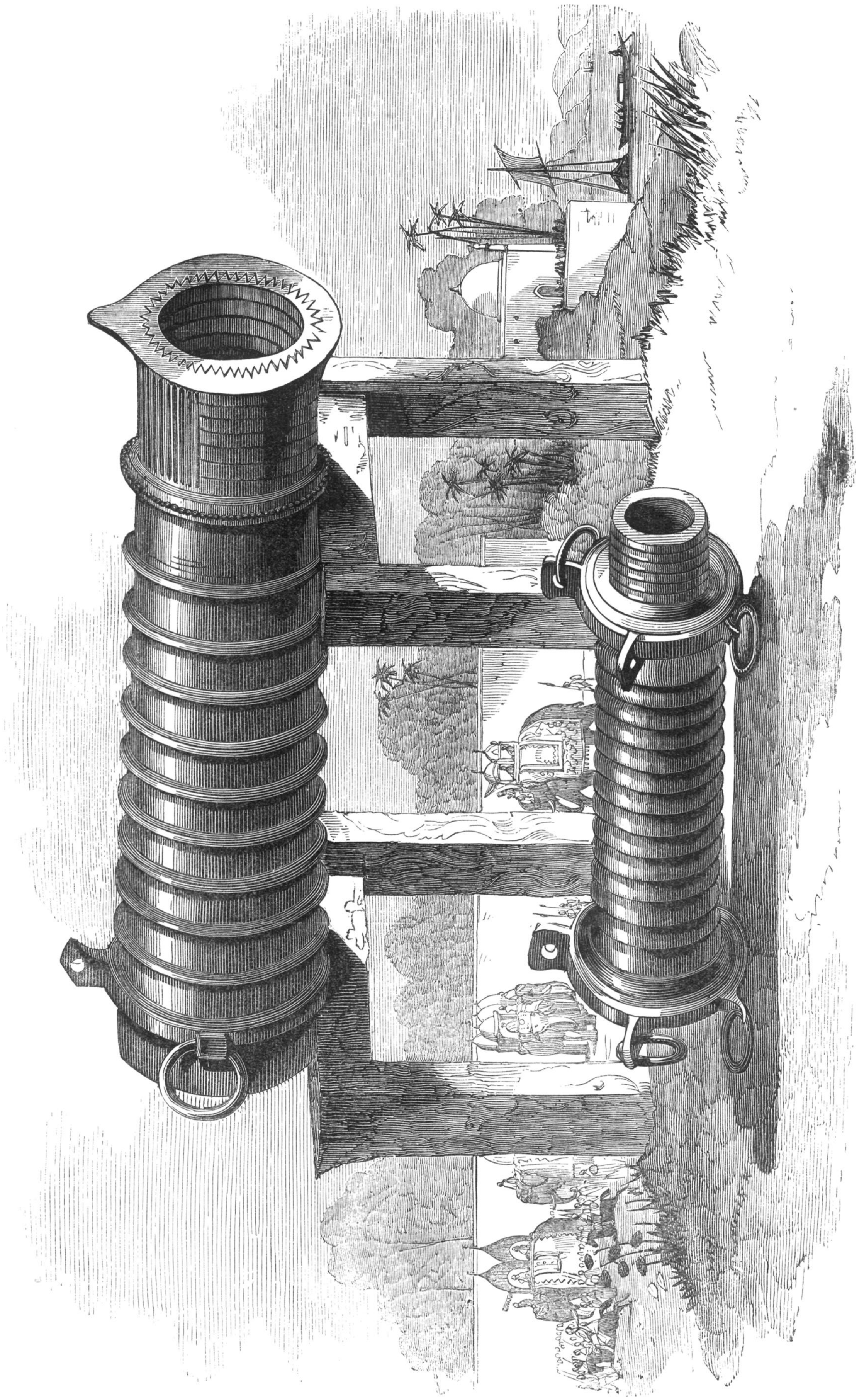
This remarkable gun was extremely well figured in the "Illustrated London News" of October 18, 1851, p. 501:—

It is identical in principle of construction with the Gantois gun, with the exception of the chamber-piece being separable from the chase, to which it is capable of being confined by lashings, through rings provided on it and on the chase.

The chase part is 12 feet 6 inches in length; the caliber $18\frac{1}{2}$ inches; the chamber-piece is 4 feet 3 inches long. Nothing is known as to the origin or history of the gun, though a vague local popular notion exists of its having been made to resist the Mahrattas, who at former periods used to descend upon Moorshedabad; but as the Mahratta power only began to rise in the middle of the seventeenth century, on the decline of the Mogul dynasties, when cannon of a totally different and more modern sort were in common use in India, this is out of question.

This most remarkable gun, identical in principle and in mode of construction with the ancient bombards of Europe, proves its own Oriental origin and construction, by the unmistakable style of ornamentation upon its exterior. Either it was made in India; or, if made

PLATE IX.



The Great Wrought-Iron Gun of Moorshedabad.

in Europe, at a period before the wrought-iron bombard was disused, transmitted to India, and ornamented by Indian artists there. The weight of the gun, the small size of sea-going vessels in the fourteenth century, the partial overland route to India alone known, the difficulty of transport over that—all make its formation in Europe most improbable. We must conclude, then, that this gun was designed and made in India; and we cannot conclude it later in date than the end of the fourteenth century. Did Europe, then, independently, discover a mode of construction in cannon, of a complex character, *identical in all its details* with the modes invented in Asia (as it has been said she did gunpowder)? or did Asia in this case learn from Europe? or must we come to the conclusion that Asia was the discoverer and the teacher, and that the identity in general dimensions and proportions, as well as in all the details, of a very remarkable construction found in the bombards of both continents, is due to this—that they were long known and in use in India and China; and that both the serpentine and the bombard were, like gunpowder, and along with it, eastern inventions, imported to us.

Colonel Symes, in his "Embassy to Ava, in 1795," informs us that he found, that "cannon, formed of prismatic bars of wrought-iron hooped together, were known in India from a remote antiquity." Du Halde mentions such bombards at the gates of Nankin, as so ancient, that their use had apparently been forgotten; the Fort of Chittoor, and others, and many strongholds in China, present to this day "fire tubes," which are the real ancestors of the serpentines of early Europe, though the latter became varied and modified, and mounted to suit European wants and modes of transport.

If cannon, as the corollary of gunpowder, were invented by its reputed European inventors, or near their seats, we should find the progress of the discovery, as it got rapidly into use, spreading over Europe, from England on Saxony as centres; but the fact is not so. The following dates of the ascertained use of ordnance, in various parts of Europe, all corroborate the view, that the great invention was brought into Europe through Spain, the Levant, and South-eastern Europe, and through the naval or commercial cities of Northern Italy; and passed into Northern Europe through the great trading and naval nations of the north:—

A. D. 1118 to 1135. The Moors in Spain use artillery in attack and defence of fortified places (Condé's "Hist. Moors in Spain").

1157. The Spaniards have artillery at the siege of Niebla, held by the Moors.

1156. The Moors use artillery at siege of Bona, in Sicily.

1249. The Arabians in Egypt, have artillery.

1280. Cordova besieged with artillery.

1308. Ferdinand IV. took Gibraltar from the Moors with artillery.

1311. The City of Brescia defended by bombards, obtained probably from the Venetians.

1312. Baza, in Spain, attacked with artillery.

1319. The Genoese possess artillery.
1326. Martos, in Spain, so besieged.
1327. Artillery used in Scotland.
1335. In use in England.
1339. In use in France.
1340. At Tariffa and Algesiras.
1343. The Tunisians use it against Seville.
1346. In Flanders generally.
1350. In Italy generally.
1353. At Nuremberg and Augsburg.
1354. In Denmark.
1356. Throughout the greater part of Germany.

Thus we observe its progress northwards and westwards, and that it reaches earliest, the most mercantile and voyaging peoples.

It seems like the whispered augury of future greatness, when we find that the ancient English fleet was armed with artillery in abundance, before it was in extended use, by any of the fleets of Northern Europe, though probably long before that time the Genoese galleys had been so provided. The Moors had cannon at sea in 1342; the English fleet in 1347; the Arragonese in 1359; the Danes in 1361. The popular statement, repeated from book to book, that cannon were unknown in France before the battle of Cressy, when they were first used by the English, is certainly an error; for Daniell, "Vie de Philip de Valois," quotes the "Chambre des Accompts" of Paris, "for four great cannon for Harfleur" in 1338.

Scotland very early figures in the list, and probably got her early intelligence, through her constant intimacy with France and Italy, and perhaps, by the prevalent transit of pilgrims to her northern shrines.

I find it impossible to give authorities within the limits of a Note.

Cannon of Bronze.

The earliest bronze guns appear to have been cast in Europe about 1370, and seem to have been produced about the same time in several of the wealthy burgher cities of Germany and of France. Between that and 1400, bombards were cast (after the more ancient models of iron) in bronze, with separate and with attached chambers (*canons a boite,*) the ancestors of all modern breech-loading guns; and culverines, which replaced the iron serpentines, and were of enormous length, 35 to 60 calibers, and great strength towards the breech, but of small caliber. Many examples remain of a later date; one at Dover Castle; another in the Dial-square, Woolwich Arsenal; and the celebrated one of Nancy (1598), above 21 feet in length (Piobert "Traite," Fig. 48), carrying about an 18-lb. iron ball.

Froissart mentions one of 50 feet in length; but in this there surely must be some

mistake. The earliest bronze guns, both in Europe and Asia, were cast without trunnions, dolphins, rings, or breech-buttons. The recoil was resisted by the flat breech abutting firmly against the heavy timber stocks on which they were mounted.

About 1378 the first examples occur of the adoption of spherical shot of cast-iron. Cast-iron, as a peculiar form of iron, and its capability of being fused, had long been known; the possibility of moulding and casting it into determinate forms must have early resulted from the daily observations of the workers in the smelting forges on the Catalan method, and in those of the Thuringian forest; though but little early use appears to have been made of a discovery upon which so much of the subsequent power and progress of mankind have depended. The stone balls of the archaic artillery, however, light, brittle, irregular in form and texture, slow and costly in formation, found a valued substitute in cast-iron, which seems to have been first used in France by Les Freres Bureau, about 1429, under the Maid of Orleans, in the wars with the English (L. Napoleon, "Passé et l'Avenir d'Artillerie").

The increased density of iron over stone, rapidly necessitated the reduction in caliber of the older bombards. The manufacture of powder was improving as it became an established European want; saltpetre was better known, and rather less impure; the original wrought-iron guns were no longer safe. The facilities which moulding and casting in bronze gave, suggested the advantage and use of trunnions and of dolphins or rings, whose formation in wrought-iron was so difficult, and of uniting the chase and chamber into one mass, which in bronze were easier made together than in separate fitting pieces, and thus heavy artillery assumed something like the general form of cylindric bore and conic exterior that it has ever since borne.

The large reduction in caliber, due to the change of material in shot, increased the facilities of using bronze, in the same proportion that it rendered practically difficult the adaptation of the ancient method of built-up wrought-iron cannon. With the then known methods of smelting and of working iron, bronze guns were now, in fact, the cheaper mode of construction, notwithstanding the higher price of bronze, which, however, was relatively nearer in price as raw material to iron than it is now. The bronze gun was found less dependent upon the care and skill of the workman at every step, and the power of ornamentation was given. Perhaps potentates and powers saw, too, that in bronze guns they possessed a material capable of conversion into treasure at any moment. These, and other minor circumstances, all tended to the rapid increase of bronze artillery, and to the neglect and final abandonment of that of wrought-iron. By 1450, the former were in common use; and by the end of the fifteenth century the latter had fallen wholly into disuse. An interesting example of the transition period occurs at the Repository, Woolwich, in one of two wrought-iron hoop guns (about 12-pounders) of the time of Henry VI., 1422. These guns are about 8 feet long, nearly cylindrical externally, with two plies of longitudinal bars, and one of hoops. One of them is imperfect; the perfect one has a

wrought-iron breech; the other, a breech formed of a bronze plug, cast into the iron, thus combining in one gun the two metals.

The causes which led to the change have not, that I am aware of, been previously viewed in this light; and I enlarge upon them because, in many important works upon modern artillery, the abandonment of wrought-iron, at this early period, has been, by a misconception of its causes, made, falsely, an argument against the advantages of wrought-iron as a material for ordnance at this present day, forgetful utterly of the vast difference between the materials, tools, and workmanship, of the blacksmith M'Kin and his sons, and the iron works and workshops of our England of to-day.

The bell-founder's art, kept alive throughout the Dark Ages by the use of large church bells from the sixth century, was at once applicable to the casting of guns in Europe. In the east, and amongst the Arabs and Turks, there was nothing to learn,—bronze-founding had existed, and been in continual use throughout Asia, from the days of Tubal.

We find, therefore, at the earliest period of bronze artillery, in Europe and the Eastern Empire, castings made of a magnitude that has never been surpassed since. Gun-founding in bronze, upon an equally large scale, had most probably been known in India from a long anterior period.

At Marienberg, in Saxony, as early as 1408, a bronze gun, of more than 6 tons, was cast; at Sienna, a gun, with separate chamber, carrying a ball of 375 lbs., and of a total weight of 11 tons; 50 and 100-pounders, at Gand and Amsterdam. The crafty and energetic Louis XI. had bronze bombards, throwing an iron ball of 500 French lbs., and twelve very heavy guns of position, three, cast each, at Paris, at Tours, at Orleans, and at Amiens, all between 1400 and 1500.

These guns, as well as some of Francis I., had no breech buttons (La Martilliere, t. i., p. 245),—a proof that even yet (though, perhaps, with trunnions) the recoil was chiefly received against the breech. These guns were usually cast with the muzzle downwards, and upon a core, as was the case with a very large gun of nearly the same form, but of eastern founding, and with oriental inscriptions in relief, taken by us at Acre, and now in the Proof Department Square, Woolwich Arsenal.

The next century saw the greatest advances in the power of artillery, of any equal period since its introduction. The corning or graining of powder, long in use for small arms, was now substituted for the dusty meal powder, which had alone been previously used for cannon, and universally applied on the Continent, though its adoption in England does not seem to have occurred until about James I.'s time. (See "Tartaglia," and Preface to Robins' Tracts.)

Charles VIII., Louis XII., and the Emperor Charles V., constructed large and effective siege trains, and the first really field trains, "marchant sur l'affuts."

Guns of the heaviest class were still cast: at Milan a 70-pounder, at Bois le Duc another,

at Berlin an 80-pounder, at Malaga another, at Bremen two 60-pounders, at Rome in St. Angelo a 70-pounder,—all date from this century, and show how diffused and uniform, all over northern and central Europe, the size and form of artillery had become.

In England, the earliest bronze guns are said to have been cast by one John Owen, in 1535, and that he was the first to produce a gun in cast-iron, about the year 1547.

I cannot find anything certain, however, as to the earliest production of cast-iron guns. Blast furnaces ("haute fourneaux") for smelting, replaced the old Catalan methods, about the commencement of the fifteenth century; were known in the Hartz, in Westphalia, in Flanders, and seem to have comė to us thence, and were not uncommon about the middle of the century. Their working must have become well known by experience, and the conditions of yield, or quality of metal, pretty certain, before it were possible to produce cast-iron guns of large size.

I know not what may be the earliest ascertainable cast-iron artillery in existence, or what records there may be of first essays. There is in the Repository at Woolwich an 18-inch *Pierriere*, captured at Corfu, with the date 1684 upon it,—an early example of cast-iron. Some old cast-iron 32-pounders, cast in Charles II.'s time, 1660–1684, are mentioned by Müller ("Introduc. Artill.," p. 22) as existing in his time. I believe there is also at Woolwich an old cast-iron gun, of late in Elizabeth's reign. The vast extensions in number and power of guns, which the use of cast-iron has produced, however, seems mainly due to England, Scotland, and Sweden, and to belong to a comparatively very recent date.

In the sixteenth and seventeenth centuries the multiplicity of sizes and forms of guns was extraordinary.

In England they might be reduced to the following classification and average sizes, dimensions, and weights.

	Length.	Caliber.	Weight.
	Feet.	lbs.	lbs.
The Cannon Royal, or Piece of Eight, .	12	48	8000
The Demi Cannon, in three sizes, . .	12	36	6000
The Culverin, in three sizes, ...	12	20	4800
The Demi Culverin, in two sizes, . .	11	10	2700
The Saker, ...	10	6	1500

The smaller sizes were called Minion, Falcon, Falconet, Rabinet, and Base, the last of which only carried a 5-ounce ball of lead.

Collado states, that at the siege of Milan, by the Spaniards, 200 different sorts of ammunition were required for the artillery. Christobal Lachuga, at the beginning of the seventeenth century, endeavoured to reduce the Spanish artillery to six different calibers only—a reform which has been recently carried to its limits, with admitted advantage, by the Emperor Napoleon, reducing the whole French field-train to one caliber of 12-pounders.

To return to the period of the text to which this prolonged Note refers.

At periods anterior to the casting of bronze guns in Europe, cannon of enormous magnitude appear to have been cast in India, by the Arabs and Turks. Colonel Symes mentions a gun at Arracan, captured from the Burmese, 30 feet in length, 10 inches caliber, and $2\frac{1}{2}$ feet across the muzzle, which bore the appearance of great antiquity. The Indian guns, however, of which I have ascertained the dates, are of a later period.

The great bombard mentioned in the text (and by Gibbon, "Decline and Fall," vol. xii., p. 197), as cast for the siege of Constantinople by the Turks, is stated elsewhere to have thrown a stone shot of 600 lbs. weight. This would agree better with 11 palms circumference of the shot, than 11 palms caliber, as stated by Gibbon and others, and coincide pretty well with the guns brought by Mustapha against Malta, of 200 to 300 lbs., and with those now at the Castles of the Dardanelles, which are probably of a not much later epoch. Of these Bishop Pococke, in his "Travels in the East," gives the following account:—

"Guns at the Natoli Eski Hirsar.—Fourteen guns of brass, without carriages, loaded with stone balls; eight others towards the south; two very fine ones amongst them, one 25 feet long, adorned with *fleurs de lis*, which they say was a distinction used by the Emperors of the East before the French took these arms, and I have seen them in many parts."

Is it not more likely that these guns were captured from some of the orders of Christian knighthood at Malta or Rhodes?

"The other is 20 feet long, in two parts, after the old way of working cannon of iron in several pieces. The bore of this is 2 feet, so that a man may sit in it; $2\frac{1}{2}$ quintals of powder are required to load it, and it carries a ball of 14 quintals."

This would be about the weight of 2000 or 2500 lbs. for a stone shot of that diameter.

"At the new Castle in Asia, near the mouth of the Scamander, are some very fine brass cannon, the bores not less than 1 foot in diameter. There are twenty-one of them to the south-west, and twenty-nine to the north, faces."

These guns have also been described by Baron de Tott; but the most interesting account of them that I have met with is that of Baron von Moltke, major in the Prussian service, in his work "The Russian Campaigns in Bulgaria and Rumelia in 1828–29," p. 528.

"The batteries on the Dardanelles, contain one hundred and eight 44-pounders, nineteen 60-pounders, thirty 121-pounders throwing iron balls, besides 63 kemerlicks or guns which throw stone balls, some of which are 1570 lbs. weight. These gigantic guns are some of them 28 inches in diameter, and a man may creep into them up to the breech; they lie on the ground on sleepers of oak, instead of gun-carriages, with their butts against strong walls, so as to prevent the recoil, as it would be impossible to run them forward again in action. Some of them are loaded with as much as 1 cwt. of powder.

"Baron de Tott gives a somewhat high-flown description of the 'earthquakes' produced

by their discharge. In the most of them the touch-holes are as large as the barrel of a musket; the great mass of powder ignites slowly, and a good deal of it is always blown out of the mouth.

"The report is very violent, but dead, and is not nearly so painful to the ear as that of an 18-pounder in a casemate.

"It is easy to follow the ball, blackened with powder, with the eye, and it is frequently seen to split into two or more pieces; huge jets of water are thrown up when it strikes the surface of the sea, as the ball, fired off in Europe, slowly ricochets across the water till it reaches the Asiatic shore.

"These giant cannons of the Dardanelles have this disadvantage, that they can only fire straight before them, and that they take very long to load; but then the effect of a single ball that does hit, is tremendous.

"When Admiral Duckworth sailed through the Straits in 1807, all the preparations for defence were of the most wretched description; nevertheless, his fleet suffered considerable injury, especially from the kemerlicks; a granite ball of 800 lbs. weight, 2 ft. 2 in. in diameter, to the great astonishment of the sailors, broke through the whole *bed for the anchor* (carried away the bitts, probably?) on board the Active, and, after crushing this mass of strong timber, rolled slowly across the deck. Another ball carried away the wheel of the Republic, and killed or wounded twenty-four men.

"The mainmast of the Wyndham was carried away, and the forecastle of the Royal George, a 110-gun-ship, was shattered by a single ball, so that she was near sinking, and could only be saved by very great exertions. Our readers are, no doubt, aware that in sea-fights the holes made by the cannon-balls below the ship's water-line are plugged by men appointed with conical pins of wood to prevent the water from pouring in. But it would manifestly be impossible to plug a hole $2\frac{1}{2}$ ft. in diameter."

I have quoted Moltke at length, as indicating the views of an experienced Prussian officer, as to the value and effective power of guns of this large size, projecting balls at a very moderate velocity; both which have been very commonly sneered at by artillery authorities. The last two years, however, have seen the introduction of iron-cased floating batteries (said also to be due, in conception, to the genius of the Emperor of the French), which, so far as they have been tried, bid defiance to the effects of any of the usual sizes of siege or battery shot propelled at high velocities.

If we are to make the means of defence, again, equal to the means of attack which these batteries have developed, it must be by providing our own strongholds and harbours with the means of throwing shot and shells of enormous weight and at low velocities (500 to 800 ft. per second), whose momentum shall not be arrested, or the shot shattered against and by the inertia of the iron plates, but shall at a blow crush in a large portion of the side, driving in both plates and timbers before it. Neglecting this until the hour of future peril

shall arrive, we may find we have in these new floating batteries animated a Frankenstein for our own destruction.

Returning to our trace of the progress of Indian gun-founding. In the latter end of the sixteenth and throughout the seventeenth century, when the Mahommedan invading powers had attained their greatest developments in power and wealth, the magnitude of many of the guns cast by native monarchs or rulers is surprising, and the peculiar character impressed by the habits of the country on some, not less interesting. Thus, at the Repository, Woolwich, there is a very fine heavy gun, cast with large loose rings, several at either side, and obviously intended to enable the gun to be slung, and carried between two elephants. Perhaps the largest bronze piece in existence is at Bejapoor (called the Moolk al Meidan, the Lord of the Plain) cast in 1685, with Persic and Arabic inscriptions in *relief* upon it, as is usual with Indian guns.

	Feet.	Inches.
Length, ...	14	3
Diameter at Breech, ...	4	10½
Diameter at Muzzle, ...	4	8
Caliber, ...	2	4

Its form appears to be that of an almost cylindrical howitzer, conical chambered, and very similar to two very large guns of which models exist in the Repository, Woolwich, cast by Captain Griffith,—one at the same place, and said to be given the same title in 1825:—

	Feet.	Inches.
Length, ...	14	3
Caliber, ...	2	0
Thickness, ...	0	12

The other, called the Great Gun of Agra, cast at the Arsenal of Admenugger, in 1820, in length, about 14 feet; caliber, about 21 inches; and the thickness about ¾ a caliber.

A gun is said to have been cast at Agra, in 1628, weighing 60,000 lbs., or nearly 27 tons, (Piobert, "Traite," p. 147); and on the Common at Woolwich stands, as a trophy, the immense piece captured by us at Bhurtpore, in 1826; for the following transcript of the inscriptions upon which, and the drawings from which the engraving of the gun has been made, I am indebted to my distinguished scientific friend, Colonel Portlock, R. E., Commandant, Royal Military Academy, Woolwich.

TRANSLATION *of the Persic Inscription on the largest Brass Gun taken at Bhurtpore, now on the Artillery Parade Ground, Woolwich.*

ON THE CHASE.

"The Father of Victory."
"The Reviver of Religion."
"Muhammad, Aurang-zeb, Alam-gir."
"The Warrior, The Victorious King."

The third line of the translation gives the three names of Aurang-zeb: their verbal meaning is:—

"Muhammad,"	Extolled.
"Aurang-zeb,"	Throne-adorning.
"Alam-gir,"	World-subduing.

"The Reviver of Religion" is a title peculiar to Aurang-zeb. The title of "The Father of Victory" was borne by Shah Alam, also; the other titles are common to all the Mogul emperors.

ON THE SWELL.

"Year of the Hejira, 1087."
"The 20th of the Reign."

1087 of the Hejira corresponds with A. D. 1677; according to Mohammedan chronologists, exactly the twentieth year of Aurang-zeb's reign.

NAME OF THE GUN, UNDER THE RIGHT TRUNNION.

"The Gun, the aid of Ali."

Ali, the hero-saint of the Indian Mohammedans, is invoked by them in every difficulty, and especially in battle. His titles are:—"The Victorious Lion of God," "The Remover of Difficulties."

UNDER THE LEFT TRUNNION.

According to the weights of Shah Jehan.
"The Ball, 30 sirs."
"Powder, 10 sirs."

The weights and measures, as established by the Emperor Shah Jehan, are those still used in Hindustan.

The sir is about 2 lbs. avoirdupois.

The verbal meaning of Shah Jehan is, "King of the World."

The gun weighs about $17\frac{3}{4}$ tons.

	Feet.	Inches.
Extreme length, ...	16	4
Caliber, ...	0	8
Diameter at base ring, ...	3	3
Diameter at first reinforce, ...	2	$2\frac{1}{2}$
Diameter at second reinforce, ...	2	$11\frac{3}{4}$
Diameter at muzzle, ...	2	0

Its proportions indicate a good deal of knowledge of the relative strains at various points along the length of the axis; but the metal is badly distributed, owing to sudden changes in the diameter, &c. Although highly ornamented, and most of the inscriptions and relievo-work well brought up, the casting is, as a gun, bad, porous, and vesicular; and the bronze is obviously an uncertain ternary or quaternary alloy. I incline to believe that it was cast upon a core, and with the muzzle down. The tasteless gun-carriage of cast-iron, painted to imitate bronze, upon which the gun rests, was made in England.

Interesting as it would be to pursue the history of artillery down from the seventeenth century to the present, it falls not within the scope of a Note, already too long; for this the great work of the present Emperor Napoleon, "Sur le passé et l'Avenir d'Artillerie;" Marion, "Recueil sur les Bouches a Feu les plus Remarkable;" and others, may be consulted. My object has been to present a sketch, only, of the origin and early history of gunpowder and of artillery, conceived, as I believe, in a more philosophic spirit than that in which the subject has been treated (so far as my information goes) by professed archæologists,—by viewing the subject, not by the mere dim lamp of scholarship only, but upon the broad principles that regulate all human material progress, and in relation to the endowments in natural substances and conditions, which have been locally given or withheld from nations, and to the great movements in time of the human family upon the earth. And thus examined, it would seem that, as in the kindred art of Fortification, no individual claim can be established to its two most salient inventions, earthwork and the bastion, but that they grew up with the necessities that called them forth;—so can no personal claim to inventorship, for either gunpowder or cannon, be sustained, nor even for priority of publication in Europe, of discoveries that most probably originated at the earliest seats and in the earliest epochs of mankind, and by the (so-called) accidental results of the observation of phenomena, produced by the reactions of some of the spontaneous productions of nature, in some of the most primitive operations or arts of man.

A second object has been, to dissipate the argument that has been drawn from the early abandonment of wrought-iron cannon, against the use of this material for ordnance at the present day, by showing what were the true conditions and circumstances that affected and produced that change.

Chronology of the Use of Wrought-Iron for Artillery.

The following chronological notices, collated from " Meyer's Historical Manual " and other sources, puts the more remarkable facts relating to the *history and progress of wrought-iron cannon* in one view, from the period already referred to, when the early wrought-iron bombards and serpentines had gradually got out of use, or rather, shortly after, when the use of wrought-iron, in other forms was revived, up to a recent date.

In 1494, Charles VIII. suppressed wholly wrought-iron bombards, and had no other artillery than that of bronze. With the exception of the occasional use of an old bombard (as in the defence of St. Dizier, in 1544), little notice is to be found of wrought-iron guns in any form for nearly a century, when they again begin to excite attention, revived in various forms.

There is in the Museum at Paris a wrought-iron piece, of 1555, very long, but of small caliber, with a movable breech.

There were at Strasbourg, in 1833, several wrought-iron cannon, bearing the date of 1602, some of which were made to load at the breech.

1621. The cannon called *abraga* are found in use, loaded by means of separate chambers. These pieces were usually of wrought-iron, and of calibers as high as 100 lbs. Sarti saw some at Gand and at Amsterdam, one of which weighed 33,000 lbs., where they were used principally on board of vessels. Venice had many pieces (50-pounders) of this kind on board of her galleys, where they were mounted on carriages. The chambers were of wrought-iron or bronze, three for each piece. They were fixed in behind by means of wooden wedges; at the moment of firing, those serving the gun stood on the sides. Those of the Mary Rose were of this class.

In 1660, there was cast in India a large bronze cannon, with a *wrought-iron lining* to the bore of six inches diameter, weighing 7726 lbs.

There is at Berlin a wrought-iron piece, of the year 1661, for a 2-oz. ball, and rifled with thirteen grooves, with a screw breech, and a sight turning on a hinge.

There was at Woolwich (in 1830) a wrought-iron piece, made at Nuremberg, in 1694, and at Zurich, of the same date, an old wrought-iron cannon, composed of many pieces, easily separated from each other.

In 1697, there were made some wrought-iron pieces, composed of bars wrapped round a core. An 18-pounder of this kind burst at the first fire.

In the " Recueil des Machines approvê par l'Academie des Sciences," t. iii. p. 79, an ingenious arrangement is figured and described, of M. Villons, for forging wrought-iron guns solidly, with the bore ready formed. They were made of annular discs, separately and successively welded together by " jumping," upon a maundrell. The plan has some

real merits, and might be possibly improved. It appears to have been produced about 1716; and the notice adds, that "such pieces were made by the author, at the Port de Marli, and some are in the Arsenal of Paris, in 1735."

The wrought-iron cannon made at Ocona, in 1744, stand well the proofs to which they are subjected. These cannon are now (1832) in the Museum of Paris. They are of calibers of $3\frac{1}{3}$ and $2\frac{1}{2}$ inches; 5 ft. 1 in. long. One of them weighs 210 lbs.

1747. Senner fabricates cannon of wrought-iron, the bores of which were grooved, and the bottom of the bore movable.

1753. There is at the Arsenal of Paris a handsome wrought-iron 12-pounder, the manufacture of Gentin, weighing 1600 lbs. It was made solid, and bored out.

1758. Hannoteau, in Paris, proposes *wrought-iron cannon, with the interior of the chase lined with copper or bronze.*

1760. Chev. D'Arcy ("Theor. d'Artillerie") proposes cannon of *wrought-iron square rods, wrapped round and brazed together.*

1764. There are at the Arsenal of Paris three wrought-iron cannon—one 12, and two 8-pounders. These pieces, made on maundrells, are composed of longitudinal bars, covered with rings, the whole welded together.

1765. Anciola caused to be made at Paguloga, in Spain, three wrought-iron pieces, one 4-pounder, long, one 4-pounder, short, and one 8-pounder. Bars of iron were used, of $1\frac{1}{2}$ inches in thickness. These pieces, forged solid, and afterwards bored and turned, sustained without injury the proof-firing, with charges of two-thirds of the weight, and the whole weight of the ball. A royal order directed the fabrication, in the same manner, of two 24-pounder cannon (weight, 20 quintals, 4400 lbs. English), two 16-pounders (19 quintals, 4180 lbs. English), and two 12-pounders (16 quintals, 3520 lbs. English). Some of the pieces were cracked in the proof. In one of these a new breech was put, and it stood proof. They were forged by hand.

There was at Paris, in 1830, a very handsome wrought-iron mortar, $6\frac{1}{2}$ inches bore, weighing 220 lbs., and made in 1775 at Madrid, by Ortega. The collection at Woolwich contains a German wrought piece of 1775.

Texier de Norbec saw at St. Sebastian, in 1780, wrought-iron cannon proved at that place in 1766, and which had remained since that time under an open shed. They were, he says, but little affected by rust.

1782. In France much interest is taken in wrought-iron pieces. Langevin makes two 4-pounders to the order of Marshal de Castries; and Bradelle, of Bordeaux, made many for the owners of privateers, at the rate of twenty-five sous per pound.

1792. The celebrated Monge, in his large work, "Description de l'Art de Fabriquer les Canons," strongly advocates the advantages of substituting wrought-iron for bronze; and adds, that the trials made in France at the forges of Guerigne, and at those of Cebada, in New Castile, had been crowned with success.

1796. In France, bronze artillery proves again to be of little durability. La Martilliere supposes that at the peace there will not be less than 1410 of these cannon to be recast, being completely unserviceable. He proposes to make, of wrought-iron, small chambered pieces, such as were formerly used at sea, loading at the breech, to replace them.

1804. They manufacture in France wrought-iron pieces.

1812. Fabrication of a wrought-iron 3-pounder at Gleiwitz.

1813. In France the Iron Company of St. Etienne offers, during the frantic efforts made to restore the vast materiel lost in 1812 by Napoleon I., and instantly required for the impending campaign, to deliver daily eight 24-pounders of wrought-iron. An 8-pounder, presented for trial, sustains four discharges with 3 lbs. of powder, and five with 4 lbs. This piece appears to have been composed of *bars wound round an inner welded iron tube, and joined into one mass with silver solder*, and a screw breech. The cost of fabrication was not to exceed that of recasting bronze pieces.

1820. Professor Persy, in his Notions on the Forms of Cannon, proposed to forge iron pieces on a core.

1820. Mallet and Pottinger supply wrought-iron 3-pounder guns, forged in one piece with screw breeches and flint locks, for the Coast-guard Service in Ireland, to the British Government.

1828. Horton takes out a patent for wrought-iron cannon. The wrought-iron cannon made at Gleiwitz in 1812 is proved. It becomes much heated, and cracks; but sustains, notwithstanding, a great number of rounds, with a charge of powder half the weight of the ball.

1830. A cannon made of bar iron, wrapped spirally, and soldered with copper (hard soldered) does not sustain the proof fire.

Meyer, in his "Experiences sur les Bouches a Feu," &c., says:—Mr. Rhodes, a skilful and practical naval constructor, employed for some time by the Turkish Government, states that there are (in 1834) in the Arsenal at Constantinople, many wrought-iron cannon, of calibers varying from 100-pounders to the smallest sizes, which are no longer considered suitable for service. By direction of the Sultan, some of them have been cut up, both in cross sections and longitudinally, to ascertain the manner of their fabrication. They were found to be composed of bars surrounded by bands, like the staves and hoops of a cask,—the whole united together, those of larger size being formed on a maundrell, and the smaller ones forged solid, and bored out. There were several successive series of these bars and hoops, laid on each other to make the requisite thickness of the metal, and the junctions of these layers, as also of the bars and hoops of the same layer, were distinctly perceptible.

1843. The large wrought-iron gun, which afterwards burst on board the Princeton, is constructed by Messrs. Ward, of Massachusets, U. S.

1845. This gun is replaced by one forged by the Mersey-steel Company, Liverpool, which stands the proofs.

1845–47. Treadwell, Mechanical Engineer of the United States, proposes and carries into effect the manufacture of wrought-iron cannon, by an improvement of Villons's process, welding together successive hollow disks of wrought-iron on a maundrell, by the pressure of an hydraulic press, in place of blows; 6, 9 and 12-pounders stand proof in America, and a 32-pounder at Vincennes.

Some beautifully formed small guns, forged each in one piece, at Erzeroum, were in the Exhibition of 1851.

1852. Captain Simmons, R.E., and Mr. Walker patent a wrought-iron gun (in which it is not clear what is the patentable novelty). The gun itself, made for Government, a 32-pounder, stands repeated trials at Shoeburyness. The gun-carriage, of iron, is very similar to Perring's, patented in 1817.

1854. Innumerable propositions are made for the construction of wrought-iron guns, some of which are submitted to trial at Woolwich, and fail. Amongst these propositions are:—

Wrought-iron guns of wire wrapped round an iron tube, brazed or not.

Wrought-iron, lined with tubular chase of bronze.

Bronze gun lined with wrought-iron tubular chase; this was done at Strasbourg a century ago, and failed.

Welded twisted barrels, formed by screwing into each other spirals of triangular section, one being reverse to the other, and then welding.

Wrought-iron guns, formed of boiler-plate wrapped upon itself, or upon a central tube, and many other such schemes.

Mr. Nasmyth undertakes an enormous gun of 13 in. caliber, and fails to forge it.

1855. An 8-in. gun, forged of wrought-iron at the Gospel Oak Works, bursts at Woolwich at proof. The iron of fine, but unfit quality; welding largely defective. (See Note Q.)

Dundas and others produce solid forged guns (9 and 12-pounders) for proof at Woolwich.

1856. While these sheets are passing through the press, Messrs. Horsfall of Liverpool have completed and proved with a solid shot of 300 lbs. and 45 lbs. of powder, an enormous wrought-iron gun, 13 in. caliber; $13\frac{1}{2}$ ft. length of chase,—perhaps the largest and most remarkable forging ever made; and two wrought-iron mortars of 36-in. caliber, built up of separate pieces, on principles developed in the text, from the author's designs, are nearly completed for the British Government.

Note referred to in Page 314.

"*Early Use of Charcoal Fuel.*—There are five different words in the Hebrew Bible which are all rendered "coal" in the Authorized Version. Of these, שְׁחוֹר (schehhor), which is found in Lamentations, iv. 8, does not come under consideration here, the exact meaning of the term being 'blackness,' as it is correctly translated in the margin. With regard to the remaining four, viz.—פֶּחָם (pehham), גַּחֶלֶת (gahheleth), רִצְפָּה (ritzpah) רֶצֶף, and רֶשֶׁף (reschiph), we cannot gather any clear idea from their *derivation*, as to the *nature* of the *substance* meant.

"The first term, פֶּחָם, is used to signify both *carbo* and *pruna*, i.e. coal or fuel, either not ignited or in a state of combustion; but it seems more properly to denote the *former;* the root signifies, '*to be black.*' In Proverbs, xxvi. 21, we meet the following passage:—'As coals (פֶּחָם, *carbo*) are to *burning coals* (גֶּחָלִים, gehhalim, *prunæ*), and wood to fire,' &c. From this passage, by itself, we might possibly *infer* that the פֶּחָם, 'coal,' as distinguished from the עֵצִים (ētsim 'wood,') implied something of a *mineral* nature, especially if we couple the idea of '*blackness*' with that of *fresh, not yet ignited* fuel. The term גַּחֶלֶת (gahheleth) is that most commonly adopted to signify 'burning or lighted coal;' and it certainly, in the majority of instances, is used in reference to *wood:* e.g.—Isaiah, xliv. 19:—'I have baked bread on the coals thereof,' i.e. on the coals of the same *wood* out of which the idol was made. And again, Psalm cxx. 4, coals of juniper, גַּחֲלֵי רְתָמִים (gahhale rethamim), i.e. of *juniper wood*, which, like the *tamarisk* among the Arabs, was supposed to make the hottest and most lasting fire. The 'coals of fire from the altar,' Levit. xvi. 12, seem to mean lighted billets of wood.

"The term רִצְפָּה (ritzpah) is found only, I believe, in Isaiah, vi. 6; and there our English version renders it 'a live coal;' but the lexicographers say, that it rather means 'a *heated stone*,' the derivative pointing out a stone such as was used in forming *tesselated pavement.* A word of kindred form and origin is met in 1 Kings, xix. 6:—'Elijah looked, and behold a cake baken on the coals,' עֻגַת רְצָפִים (uggath retzaphim), literally, a cake (baken) on *stones*, heated stones. As for the last word, רֶשֶׁף (reschaph), translated 'coals,' in Deut. xxxii. 24 (Marg.), Song of Solomon, viii. 6, and Habak. iii. 5, it rather means the *heat* and flame of fire, than the material producing it."

To my learned friend, the Rev. William Carroll, A.M., Vicar of Glasnevin, county of Dublin, I owe the above.

I have abstained from any similar attempt to ascertain the earliest notices of nitre, as to which a great deal of learned, but, to our subject, not very pertinent matter, may be found in Beckmann, "Hist. Invent.," because, however important it would be to the history of gunpowder in Europe to ascertain *whence its early supplies of nitre came*, the question of its earliest written notices in Europe are unimportant; and in Asia it existed as a widely diffused natural product always; it would, therefore, be impossible to show a time when it was not known in this, the seat of the first known use of gunpowder. —R. M.

Note B.—(Sect. 1.)

Shell guns, almost limited at first by their chief proposers to the subordinate place of throwing hollow shot or shells, at moderate velocities and low elevations, against earthworks, but principally against shipping, where the shattering and splintering effect of such projectiles is legitimately applied, have had, within the last ten years, a preponderance in number and application given to them, especially on board ship, the evils of which Sir Howard Douglas has fully exposed in his "Treatise on Naval Gunnery."

In place of whole tiers of hollow shot guns, of large caliber, of proportions unsafe for, or even incapable of bearing, the discharge of solid shot, with full service charges, the improve-

ments in naval construction, as well as the necessities of coast attack, developed within the last year or two, have forced attention to the necessity of providing our ships with guns, that shall throw solid shot of the greatest possible weight, and with the highest velocities and longest ranges.

After lengthened experiments and many difficulties, it had been found that shells, up to 10 inches diameter, could be thrown at nearly horizontal ranges, and at high velocities, from shell guns. The success was pushed too far. It was said that the new method rendered useless the older notions of throwing shells by vertical fire, and that mortars were no longer needed. The result was, that when the hour of trial came, we possessed scarcely any mortars, and no mortar vessels, and did not know how properly to construct either. Experience, gathered when it had become too late to employ it, proved how widely we had erred, in abandoning and underrating the ancient methods of bombardment.

So far from being fitly abandoned, it soon became evident that the adoption, upon a larger and more extended scale than had ever before been known, of the system of casemated fortifications, for coast line fortresses, on the part of the enemy, would compel us to reinforce the ancient powers of vertical fire, by increase of range, velocity of descent, and weight of shell, if we were to produce any effect in that way upon these formidable defences.

Upon examining into the comparative increase of effect that might be expected from increase of diameter of shells, above those ordinarily in use, I found, with some surprise, that the military literature of Europe, so far as I had access to it, did not contain an attempt even to ascertain this in a rigid manner. Tables, indeed, exist in foreign services (imperfectly in ours) of the range, deviation, penetration, &c., of the three or four sizes of shell, long in common use; but it does not seem to have ever occurred to any military author to discuss these into general laws with relation to the variable diameter of the shell; or if, admitting their basis to be too narrow for such a discussion, to determine, *a priori*, the physical and dynamic laws which, applied to shells of different magnitudes, would enable such a comparison of effect to be made.

Having proposed to Government, about the latter end of 1854, the construction of shells and mortars of 36 inches diameter, for certain special services, I found it necessary to make some such investigation, to compare the effects of shells of 36 inches diameter, and of given proportions, with the largest existing shells then in the British service, viz., 13 inches diameter.

The following is an abstract,—I make no apology for adding it to this Note, as forcibly indicating the value of increased magnitude in hollow projectiles, and of vertical fire.

Relative Powers of Shells, in proportion to their Dimensions.

In the attack of fortified places by bombardment, the efficiency of similar shells, thrown with equal address, would seem to depend upon—

1°. Penetrative power, which, unlike that of solid cannon shot, does not depend solely upon the nature of the resisting medium, the diameter and velocity of the ball, but in the same medium is a function of the diameter and weight, or density, and of the velocity of descent.

2°. Explosive power, in the direct ratio of the weight of included powder.

3°. The levelling power, or extent of the area of demolition, a function of the explosive power, or of the weight of included powder.

4°. The fragmentary missile power, dependent upon the mass, average number, and distance, to which the fragments are thrown.

5°. The moral effect, resulting from and proportionate to, the destructive effects of each explosion, and upon the degree in which it is possible to guard against or to escape them.

With spherical, similar shells, and charges, it is probable that the penetrative, explosive, and missile powers increase, at equal velocities, with the weight of iron and of powder, nearly as D^3 (the external diameter), within certain moderate limits; but when the diameter of the shell shall greatly exceed the largest hitherto employed, the powers upon which the efficacy of the missile itself depends will be found to increase in a far higher ratio. The maximum range, due to projection at equal angles, and with proportional charges of powder, will be found also to increase with D.

From the middle of the seventeenth century when Malthus,—an English gentleman, and apparently not a soldier,—having learned the practice of throwing shells in Holland, perfected the system for the French (being the first to throw them in France, at the siege of La Mothe, in 1643), up to the present time, but very slight modifications appear to have been made in the diameters of shells in established use throughout Europe. Borrowed from the old French standard of a Paris foot in diameter, the 13-inch shell appears to be about the largest employed in any service. England, Hanover, Spain, Russia, and Sweden, use shells larger than those of the other European powers, and those of Russia and Sweden a little exceed all the rest in size.

Hollow projectiles are said to have been used, on the earliest recorded occasions—at Naples, 1495; at Padua, 1509; at Heilsberg, 1520; at Mézieres, 1521; at Rhodes, 1522; and at Boulogne, 1542; and were made of wrought-iron, of bronze, of alloys of lead and tin, and finally of cast-iron, as now. Although limited, in the seventeenth century, to the existing sizes, the preceding century witnessed the use of bombs (*cominges*) of a very much larger size. At Boulogne, as early as in 1542, shells of 19 inches, French; at Berlin, in 1683, shells of 1100 lbs. weight, existed; at the bombardment of Genoa, in 1684, shells of 1320 lbs. were thrown; and even as late as 1745, at the siege of Tournay, the French threw shells of 18 inches, weighing 550 lbs. See Valturius, "De re Militari," Paris, 1534; Gentilini, "Instruttione de Artiglieri," Venice, 1598; Biringoccio, "Piro-

technia," Venice, 1550; and Collado, "Practica Manuale del Artiglieria," Milan, 1641. The French found, on taking Algiers in 1830, numbers of shells weighing nearly 900 lbs.; and the Swedes, in 1642, used shells of 462 lbs. weight, and holding 40 lbs. of powder; and, in most arsenals of Europe, an old shell or two, from 16 inches to 18 inches diameter, may be found preserved as a curiosity.

With the exception, however, of the attempt made by the French, in 1832, to construct a 24-inch mortar, and apply it at the siege of the citadel of Antwerp, no essay seems to have been made in recent days to realize the vast increase of power that such large shells must confer; scared, apparently, by their former abandonment, which (Antoni, "Uso delle Armi da Fuoco," Torino, 1780, states) arose from the awkwardness of loading, which prevented more than one discharge in forty minutes, and from the great cost of the manufacture of such shells in the condition of iron-founding at that time. A 20-inch mortar was cast in England, some years since, for the Pacha of Egypt, a solid shot from which, on proof at Woolwich, penetrated the butt to an enormous depth; but it never appears to have been used.

The "Monster Mortar" of Antwerp, as it was called, was designed by Colonel Paixhans, and cast, at Liege, by direction of Baron Evain, Minister of War. Its form was crude; a mere cylinder, embedded in a mass of timber. The dimensions of the mortar were:—

	Inches.
Total length,	59
Diameter outside,	39·5
Caliber,	24·5
Length of chase from top of chamber,	27
Depth of chamber,	19
Diameter of chamber,	9

When afterwards burst at Braschaet, the casting was found to present those defects which, upon principles developed in the text, are inevitable to huge masses of cast-iron, suddenly varying in solid dimensions.

The weight of this mortar was 14,700 lbs.; that of its bed, 16,000 lbs.; the weight of the empty shell was 916 lbs.; the charge, 99 lbs. of powder; giving a weight for the shell in flight of 1015 lbs. The chamber of the mortar would hold 30 lbs., but about 12 lbs. of powder were found sufficient to throw the shell 800 or 900 yards. When brought into position against the Citadel, at about 1000 yards range, after one or two preliminary trials, it was found that a shell could be fired about every forty minutes, the loading being performed by an awkwardly constructed balanced lever or "chevalet." But few shells, however, were fired,—not above twenty in all,—all those provided, which had only an *average* thickness of about 2 inches, being found so weak about the "culot," or bottom of

the shell, that they rarely resisted the shock of projection, and burst near the mouth of the mortar, while the fuzes of others seemed to be bad. The very few, however, that were fired successfully, produced effects so formidable, that the capitulation, which took place before the breach was practicable, and within a few hours from the explosion of the first shell, was presumed to have been much precipitated by the persuasion of the Governor, General Chasse, of the impossibility of maintaining the fortress under their continued fire.

One of these shells fell within a few yards of the principal powder-magazine, but did not explode; had it fallen on the magazine, which was presumed bomb-proof, it was the universal opinion of military engineers present, that it would have pierced the arch. The magazine contained above 300,000 lbs. of powder: its explosion, therefore, as in the case of the magazine accidentally blown up at St. Jean d'Acre, would have settled the contest at a blow.

This mortar, than which a more unwieldy, ill-constructed, and unmanageable instrument could scarcely be conceived, was afterwards burst in experimenting with it on the Heath of Braschaet. After having been fired with various charges, from above 40 lbs. downwards,—by which it was ascertained that less than half this quantity sent the shell as far as the greater,—a charge of only 9 kilo. = 19·845 lbs. of powder, burst it.

The unsatisfactory practice of these shells at Antwerp, as the author had opportunity of knowing, arose from their defects of construction, from the extreme awkwardness of the construction of the mortar and of its bed, and of the means employed for handling and loading these heavy shells. Some experiments were made, in 1833, at Braschaet, which proved that these shells, thrown to about a range of 3000 feet, at 45°, penetrated into the solid earth of the Heath from 7 to 8 feet, and that the explosion of the bursting charge of only 55 lbs. produced a crater of about 20 feet diameter. The splinters averaged from twelve to fourteen, and were thrown an average distance of about 100 feet.

This appears to be the largest scale upon which any attempt to throw shells, of a size to be properly termed "Transferable Mines," had been made up to 1854.

The weight of a 13-inch shell in flight varies from 180 lbs. up to 230 lbs.: the Antwerp shell weighed as much as about five and a half such shells.

We are now to compare the 13-inch with the proposed 36-inch shells.

The weight of iron in the empty 36-inch shell may be assumed at 2481 lbs., and the weight of bursting-powder, supposing the internal cavity full, at 480 lbs.,—so that the total weight of the shell in flight would be 2966 lbs., or above $1\frac{1}{4}$ tons.

Assuming the angle and altitude of projection to be the same, and hence the velocity on reaching the earth, neglecting resistance of the air, the penetrative effects of this shell, as compared with a 13-inch shell, will be directly as their respective weights, or as, say, 200 : 2966, which is nearly as 15 to 1 in favour of the large shell, supposing the surfaces of impact the same.

In imperfectly elastic solids, such as masonry, brickwork, earth, &c., the resistance to penetration, immediately after impact, may be assumed to vary as something between the diameter and its square; it will certainly be much less than proportional to the areas of the great circles of the respective spheres. It will be safe, therefore, to say, that the penetrative power of the 36-inch shell will be at least sixfold that of a 13-inch shell.

Experimental data are wanting to enable any precise calculation to be made for any given material. We do not know in what way or to what extent the surrounding material is moved or compressed. A 13-inch shell penetrates solid sand and earth about 2·5 feet; the Antwerp shell penetrated such earth about 7·5 feet, or three times the depth, its weight being about five and a half times as great.

The 36-inch shell might, therefore, be presumed to penetrate at least 15 feet into compact earth; and, upon exploding, to excavate a crater of 40 feet in diameter; and, as a depth of about 6 feet in earth has been found to give the maximum excavation or crater from the explosion of a 13-inch shell, so this depth of 15 feet would give about the same result for the 36-inch.

Thrown at a low velocity, the resistance of the air, to shells in flight, is, perhaps, directly proportionate to the area of their great circles, or to D^2; or, in this case, again comparing the 13-inch and 36-inch shells, to 169 : 1296, or as 1 : 7·66, or nearly as 1 to 8.

The energy of motion, however, or their respective powers, at equal velocities, to overcome this resistance, is as their respective weights, or as 200 : 2966, or as 1 : 15 nearly.

The retarding to the moving forces, therefore, in the two shells, are as—

$$8 : 15,$$

or nearly 2 to 1 in favour of the large shell.

It is certain, therefore, that much smaller proportional charges of projection may be used for equal ranges with these large shells; and that, with equal projectile charges, the velocity of descent from the trajectory will be much greater.

The projecting charges for 13-inch shells varies from 15 to 20 lbs., the extreme range, at 45°, being 4700 yards, or 2·10 miles.

Assuming equal horizontal ranges at equal elevations, as due to equal velocities, the charges for projecting different shells with equal velocities must be in proportion to the work done in each case; or as

$$M V^2 : M' V^2$$

or as

$$M : M' \text{ when } V = V'.$$

This would give a projecting charge at maximum of nearly 140 lbs. for the 36-inch shell; but, as indicated in the text, the proportional effects of very large masses of powder are

greater than those of small bulks. Less than one-half of this charge would probably be sufficient in practice for every requirement.

As the relation between aërial resistance and momentum, however, has been shown to be as nearly 2 to 1 in favour of the 36-inch shell, there can be no doubt that, with a proportional charge, a range very much above that of a 13-inch shell could be obtained, and that an extreme horizontal range of from three to four miles might be anticipated. Such extreme ranges, however, are not the important question or advantage as respects these large shells, whose most valuable and effective uses, would probably be found at much less distances, or within a range of 1000 yards.

Before dismissing the subject of the penetrative power of these large shells, one more remark should be made.

In the destruction of buildings, &c., it is all important that the shell before explosion should enter the interior. This always involves questions of relative *inertia*, in which the greatness of the *mass* of the falling shell, as opposed to the *mass* of the body to be moved or pierced, whether arch, floor, or solid earth, are elements. It is almost inconceivable how vastly greater will be the shaking and dislocating effects upon structures, of a mass falling on them of 1½ tons weight, as compared with the insignificant weight (200 lbs.) of a 13-inch shell, which with difficulty pierces through a well-made brick arch, of moderate span, and three bricks thick. It seems probable, that not one of the casemated forts of the Russian fortresses could sustain the shock of the fall of a 36-inch shell, without total dislocation.

Authors on military architecture state that vaults of masonry of 40 inches in thickness are to be considered bomb-proof, and the tables of fire give a penetration into masonry of 13-inch shells, at extreme ranges, of only 3 or 4 inches. At the siege of Tournay, in 1745, forty or more bombs are said to have fallen upon the magazines, without doing much injury. One element, however, seems to be omitted by all authors who have treated of this subject, namely, the span of the arch, the weakness of which, to resist the shock of shells, must increase more rapidly than the width, for equal depth of voussoir, and very much must depend upon the character as to weight, elasticity, and crushing resistance, of the material itself of the arch. A heavy, moderately soft, tough brick arch, well jointed and bonded, will probably offer a much greater resistance, for given dimensions, than one of hard, elastic stone, unless the latter be in very heavy blocks.

The explosive power of any shell being, as stated, directly proportionate to the weight of powder it contains, it might seem at first that the destructive effect of the explosion in shaking and levelling buildings, &c., will have a focus or area of action in the like proportion. The explosion of a shell may be regarded, at the first moment, as equivalent to the sudden *creation* of a sphere of elastic gases, equal to, say, about one thousand times the volume of the contained powder. This produces, by its sudden expansion, a blow or pulse upon the sur-

rounding air, which is propagated outwards, in all diretions, in spherical shells or waves, moving with uniform velocity, which is about equal to that of sound in air, but with a continually decreasing range of pulse or amplitude of wave oscillation. As the distance from the point of explosion increases, the quantity of elastic matter in motion, at any moment after the explosion, must, in accordance with the general mechanical law of the conservation of *vis viva*, be equal to that in the original spherical generating wave, to whose volume that of every subsequent spherical shell must be equal also at the same phase of the wave, or at the instant of equal density. The surface of each spherical shell increases in the ratio of R^2, and if the entire phase of the wave (i. e. the oscillation to and fro) be $2a$, the impulse at any point of the surface of any spherical shell, at the distance R from the origin, is proportional to $\frac{1}{2a\,R^2}$.

The shock, or overturning power of the elastic wave, or, what is the same, the energy of the explosion in overthrowing objects, is at every point around (above the earth's surface, upon which we may suppose the shell to explode) inversely proportionate to the square of its distance from the focus of explosion. In fact, it follows the law of light, and sound in air. But the amplitude of the wave is originally proportionate to the weight of powder exploded. A determinate extent of oscillation is necessary to overturn or destroy any given object, whether it be to overturn a wall or to break a window; therefore, any such object will be overthrown by unequal quantities of powder at distances greater as the quantity is greater. This is the power of demolition in any radial direction round; and as this power acts alike within a circle having this for its radius, and whose area is proportionate to R^2, the total power of demolition, therefore, of any shell varies directly as the square of the weight of powder exploded.

Comparing, then, the 13-inch and 36-inch shells, the total power of demolition is as $12^2 : 480^2$, or as $144 : 230400$, or as $1 : 1600$; and equal demolition will take place at radial distances from the point of explosion, greater in the ratio of $40 : 1$. Nor can it be concluded from this, that the extent and character of demolition would only be that of forty 13-inch shells: for it is obvious that the explosion of the 36-inch shell will be capable of overturning or destroying objects which the explosion of a 13-inch shell, or of any number of successive 13-inch shells, however great, could never move at all.

The missile power of the shell as against fixed objects (and such shells are not intended to act against troops, but against the material, buildings, and other essentials of fortified places, or against shipping) depends upon the total weight of fragments, and on the distance to which they are projected; the latter will vary about as the $\sqrt{w}$, the exploded powder, for a given weight of shell; hence, in the 13-inch and 36-inch shells, as $190 \times \sqrt{12} : 2486 \times \sqrt{480}$, or as $665 : 54443$, or as $1 : 81$. In this respect, therefore, the large shell is above eighty times as destructive as the largest now employed.

The fragments of 13-inch shells are stated sometimes to range nearly 2500 feet (Piobert).

The number of fragments with similar proportioned shells would probably be the same from both, about twelve or fourteen; but if the 36-inch shells were somewhat thinner in proportion, the greater energy of the included bursting-charge, would produce a greater number of fragments. A few *large* fragments will, however, be generally most advantageous with these large shells. And here again, for the same reason that one heavy shot may batter down an object upon which any number of much lighter shot would produce no impression, so the *heavy fragments* of the 36-inch shell will go through, or batter down walls, &c., upon which those of 13-inch shells would have no effect whatever; besides which, the largest of the fragments of the 36-inch shells will often be flung to distances vastly greater than the average here assumed.

Upon the moral effects likely to follow the use of these powerful shells it is not necessary much to enlarge. No splinter proof, no ordinary vaulting, perhaps no casemate, exists, capable of withstanding the fall and explosion of such masses, one of which would, no doubt, sink the largest ship of war or floating battery, upon which it descended. A single shell, which fell upon "Le Terrible," in 1690, pierced through her upper decks, and exploding between decks, in its descent, clearing away much of the upper works of her sides, blowing away all the poop, and killing or wounding one hundred of her men. At the siege of Namur, in 1746, a single shell, exploding after it had buried itself (in probably, stony ground), killed or wounded thirty men. Sir Howard Douglass ("Naval Gunnery") has given many remarkable examples, also, of the tremendous effects of shells.

No precaution, therefore, could save either town or garrison, from such shells; the "rayon" of demolition of each of which would be so appalling, that it might rather be viewed as a suddenly transferred mine, than a mere shell. *Wherever* such a shell happened to alight in a fortified place, its effects would be formidable: if even on plain open ground, at some distance from buildings, it would bury itself, and its explosion dig out a formidable crater, driving the excavated contents far and wide, and rending the earth around for at least double the diameter of the crater. The shock of each explosion would extend so far, destroying windows, doors, and roofs, that the place would rapidly become wholly exposed to the weather. The undulation of the ground itself, produced by such explosions, would often be sufficient to throw down lofty buildings with narrow bases, such as columns, chimneys, obelisks, &c., beyond the actual radius of demolition.

The fuzes of such shells, may best be timed abundantly long, to insure the shells falling before they shall burst. The huge weight of the shell, defies any attempt to remove it; and the fuze-tube should be made of a size to give a volume of fire, that should defy any attempt to extinguish it, and to prevent extinction by the shell burying itself in the ground.

As respects proportionate deviation in range and in direction, and hence probability of striking a given object, it appears from the French Tables of actual practice in service, that the mean deviation of 13-inch shells, at elevations of 45°, and extreme ranges (2630 yards), is about 102 feet in range, and 152 feet in direction. It has also been found, that the probable accuracy of fire with solid projectiles, point-blank, increases in the ratio of the square of the weight, for the same density, and directly as the density of the projectile. This should also apply to the causes of deviation in *flight*, *alone*, of shells. The density of the 36-inch shell is not quite as great, in the proportions proposed, as that of the 13-inch shell, but may be made so. In that case, the probable accuracy of fire, at equal ranges, would be as $2966^2 : 200^2$, or as 8797156 : 40000, or as 219 : 1; or, at double the range of a 13-inch shell, the increased probable accuracy of fire would be about as 100 : 1.

This takes no account of any causes of deviation but those operative in flight,—making the most ample allowance for all others, the accuracy of fire of these large shells, must be assumed at least thirty times as great, as that of 13-inch shells. The French Tables of probability of shell-firing show, from a base of thirty years' practice, that of 100 13-inch shells, at ranges of about 550 yards, 3·38 shells are dropped within a circle of 25 feet diameter: at 1100 yards range, therefore, at least 45 per cent. of the 36-inch shells fired might be expected (after due experience) to fall within that circle, or within a space less than half the breadth and one-eighth the length of a ship of the line.

The cost of each 13-inch shell, in flight, may be estimated at about £2 2*s.*; and that of each 36-inch shell at about £25, or as nearly 1 : 12; but to transfer to the point of effect the same weight of bursting-powder, 55 13-inch shells must be fired; or—

55 shells, at £2 2*s.*, ...	£115	10	0
1 36-inch shell, at £25, . . .	25	0	0
Saving in favour of large shell, .	£90	10	0

And this *assumes* that the 55 smaller shells *could* do the work of the single large one.

I shall conclude and support this Note by quoting the following opinion of General Piobert, " Traite D'Artillerie," tom i., p. 286 :—

" Les mortiers, premiers bouches à feu qui soient parvenues à un certain degré de perfection, sont encore susceptibles de recevoir de notables améliorations, malgré les changements apportés, il y a soixante ans, dans leur construction. Enfin, les pierriers, qui sont les plus anciennes bouches à feu, sont restés dans un grand état, d'imperfection, et l'efficacité de leur tir, est même inférieure à ce qu'elle était, à l'origine de l 'artillerie. Il résulte de là, que les feux verticaux, qui seraient susceptibles de jouer un rôle important dans l'attaque et dans la défense des places, laissent beaucoup à désirer sous plusieurs rapports, aussi toutes les améliorations dont l'ancien matériel de l'artillerie était susceptible

dans cette partie, n'avaient pas été réalisées, lorsqu'on s'est arrête, dans la voie de modifications où l'on était entré."

The value of vertical fire from suitably constructed mortars remains yet to be fully understood and developed, as the only means of obtaining greatly extended ranges. Recent trials, proving the facility with which shells filled with melted cast-iron may be discharged, add immensely to the value of vertical fire, by providing an effective incendiary projectile, whose density is little short of that of a solid shot, and therefore capable of projection to an immensely increased range, at 45°, over any ordinary shell or hollow projectile.

As indicating, forcibly, the important results to be anticipated from increasing the weight and power of our artillery in all its species, I have deemed this Note, though long, not irrelevant to the text of a work, whose object is to point out some of the principles upon which such aggrandizements of power must depend.

Note C.—(Sect. 2.)

There have been two great epochs of increased strength in the history of gunpowder: the first, and very early one, when refined saltpetre began to be substituted for the crude salt, containing not less than 25 per cent. of inert or injurious matter; the second, dating from the sixteenth century, when the graining or corning of the dusty meal-powder, before alone in use for cannon, became common.

The sulphur of early powder, probably, did not differ very materially from that now employed; but no determinate rules as to the best quality of charcoal, or of special methods for its preparation, appear to have been established until times comparatively recent.

Motives of economy, probably, induced a parsimonious use of nitre, in most of the early powders, while this material (at all times the most costly element of powder) was collected in Europe, and previous to the opening up of the vast supplies now derived from India According to Tartaglia, at the beginning of the sixteenth century, cannon powder was composed of four parts of nitre, one part of sulphur, and one part of charcoal, which is equivalent to only $66\frac{2}{3}$ per cent. of nitre; while musket powder contained 77 per cent. For the composition of powder in the time of Cardan (1501–1575) *vide* Fred. Hoefer's "Hist. de la Chimie," t. 2, p. 101. It would be a matter of great interest to ascertain *the price of powder*, at the earliest, and for successive periods downwards, in the history of Europe.

The chief European Government powders of the present day have the following compositions:—

	Nitre.	Charcoal.	Sulphur.
England, ...	75	15	10
France, ...	75	12·5	12·5
Austria, ...	75	15	10
Sweden, ...	75	16	9
Prussia, ...	75	13·5	11·5
America, ...	75	12·5	12·5
Italy, ...	76	12·0	12·0
Russia, ...	70·6	17·7	11·7
China, ...	75·7	9·9	14·4

In 1819, according to La Martilliere, the French cannon powder consisted of—Nitre, 76; charcoal, 15; sulphur, 9; and similar slight variations of proportion appear to have occurred from time to time in other states. On the whole, however, the constitution of powder has remained very uniform for above a century; nor does either the general history of the combats of modern warfare, or the more precise experiments with the *eprouvette,* intended as tests of the strength of powder, indicate any very material difference or gradual increase in *the ranges* produced from equal charges. It appears to be an opinion, somewhat generally affirmed by well-informed British artillery officers, that the great and rapid destruction of artillery in service recently, can in no wise be attributed to anything particular in the powder; for that the records of the governmental proofs show incontestibly, that the powder of the last century, gave ranges as great as that of to-day.

This may be—is, no doubt, the general fact; but it is submitted that it is not the question. *The length of range may be the same, and yet the distress upon the gun* very different; nay, the range may be much less, and yet the distress much greater.

The rapidity of ignition is the great element upon which the latter depends, other things being the same; and *eprouvette* trials give no information whatever on this point, which seems still to demand a special train of researches, in order fully *to ascertain what quality and composition of powder shall give the greatest range with the least distress upon the gun which shall have been found best fitted to develop its full motive power.*

The rapidity of ignition is, in fact, for the same composition, almost wholly a question of molecular condition, one of greater or less subdivision and intimacy of mixture of the ingredients, of the degree of condensation of the "cake," perhaps of the crystalline condition both of the nitre and the sulphur; and, lastly, of the form, size, and character of surface of the individual grains of powder, their hygrometricity, &c.

Now, the general tendency and effect of every mechanical improvement which has been made in modern times in the machinery of powder-mills, at the suggestions of economy, safety, and expedition in the manufacture, have been inevitably to magnify such of the above conditions as produce rapidity of ignition, though, perhaps, adding nothing perceptibly to the motive effects. This was very strikingly evidenced in France, when, in the year 1828, the introduction of certain new, and, it was thought, improved, machinery into some of the

Government powder-mills (Bouchet), resulted at once in the production of a powder whose ignition was so rapid, that, after patient and careful trials, it was found their bronze guns were injured by it to such an extent, as to induce its immediate abandonment, and powder of this character is since known in France as "*Poudre brisante.*"

How far the opinion thus referred to in the text, that modern powders visit on cannon an increased distress—an increment of long and slow growth—as compared with the powders of the middle of the last century, and previous, may admit of historic or of experimental confirmation or reversal, I know not. The general impression of foreign professional writers on the subject, however, appears to me to sustain it:—

"Ce n'est donc qu'à mesure que les bouches a feu, plus solidement fabriquées ont permis de donner a la poudre plus de force, qu'on est parvenu, par le simple tâtonnement, a trouver la proportion la plus convenable au dosage des trois matieres, ce qui de concert avec de meilleurs procédes observés dans la fabrication, a successivement amené la poudre au degré de force où elle est parvenue, et ou elle est enfin restée depuis quelques années."—*La Martilliere*, t. 1, p. 6, Paris, 1819.

"Une deuxieme consideration encore plus importante, est la plus grande force de la poudre de guerre d'aujourd'hui,—qui agit plus puissamment pour la destruction de la pièce que pour chasser le projectile. Nos plus nouvelles bouches à feu ont incontestiblement plus de tenacité que les anciennes: quelques essais et la seule inspection de la cassure des dernieres qui est presque noiratre" (cast-iron guns namely), "et qui n'offre que des soufflures grossieres le prouve suffisamment; .... néanmoins les chroniques anciennes ne font aucune mention de ces accidents malheureux si frequens aujourd'hui. Sans explication que nous verrons de donner sur la force de la poudre ce phenomene serait tout-a-fait incomprehensible, d'autant mieux qu'autrefois la charge de poudre des canons etait plus forte qu'au'jourd'hui."—Moritz Meyer, *Cap. de l'Art. Pruss.*, pp. 105-6, Paris, 1834.

His editor, Peretzdorf, in a note, says that General Eble, in 1808, made comparative proofs of powder of that date, with some a century old, or more, and that the old powder was the stronger. The trial seems, however, to have been only one of *comparative range* by the *eprouvette*, and, therefore, is not in point.

Proofs made in Bavaria, of ancient bronze guns, which had stood service in former years, and yet burst with ordinary charges more recently, and were found on examination to be composed of very inferior material, with much accidental foreign metals, and to which their weakness was justly attributed, all lead to the same conclusion; however weak, they should have withstood the *same* strain at one time as at another.

One thing is certain, that civil inventors, or improvers of ordnance, or contractors for the supply of artillery, should be well aware, of this great disparity in the distress possible to be visited upon guns by apparently precisely the same charge of powder, and weight of shot.

NOTE D.—(SECTS. 3, 4.)

MUCH remains to be ascertained by experiment as to the law of development of the pressure produced by the gases of the inflamed powder up to its maximum, before analysis can do much to advance our knowledge in a way to be practically useful in proportioning the strength of guns.

Poisson published, from the MSS. of Lagrange, some important investigations on this subject in tom. xiii., p. 187, &c., of the "Jour. de l'Ecole Polytech."—"Mem. sur les Relations au Movement du boulet dans l'interieur du Canon;" and General Piobert has also brought his great mathematical and practical powers to bear upon the subject; but, partly from the algebraic difficulties of the question, and partly from want of data, which can only be obtained by entirely new methods of experiment, much is yet required to enable practical formulæ to be deduced.

The proposition of the text, which will be found further sustained by the investigation in the subsequent Note S, shows the fallacy in theory of several projectors, who, within the last five years, propose to reduce the strain upon artillery, the weight of shot being given, by conjoint diminution of caliber, and the use of elongated shot, under the notion that guns of reduced thickness can thus be made to answer.

At the same time, the valuable practical result must be admitted, in the unity and simplicity of artillery, should it be possible to construct guns of wrought-iron, or in any way, of such strength that they should bear to be fired at pleasure, when required, either with spherical or with elongated shot, of greatly increased weight. In many of the trials of elongated shot that have been made, with unfavourable results, at Woolwich, a great theoretic oversight appears to have prevailed, in continuing to use the same proportionate weight of powder for propulsion as with round shot,—one of the most important advantages offered by elongated shot being thus lost, viz., that their great momentum, and proportionably small aërial resistance, gives an equal or greater range, with a much lower velocity, than with spherical shot; and that hence the old proportionate charge of powder is not only unnecessary and wasteful, but destructive in its action upon the gun, before the inertia of rest of those heavy shot can be overcome. (See "Artillerie Nouvelle, par M****, Cap. de Artill." Paris, 1850, p. 18.)

The observations made in the United States, upon the point of greatest wear by deflagration, in the interior of the chase of Columbiads (8-inch guns), throw some approximate light upon these questions, indicating, as they do, that the spherical shot does not begin to move until a large portion, at least, of the powder is ignited, and moves through, from a quarter to one half its diameter, before the ignition of the whole is completed.

In the reference to this Note from Section 256, see also Note I., referring to Section 60.

NOTE E.—(SECT. 15.)

THE law of crystalline arrangement in crystallizable masses, announced in the text, although passing as a clue of illustration throughout this Treatise, would demand a separate work, to treat it as its important relations to many of the most interesting questions of Physics, and its enunciation, for the first time, would deserve.

To fulfil this in a Note is impossible; a few remarks should, however, be added to the text. By *principal axis* of the integrant crystal, in metallic masses in the act of becoming crystallometrically arranged, under the influence of heat, or of pressure due to its motion, I do not necessarily mean the *optic axis*, were such determinable for opaque bodies such as the metals, but *that symmetric axis of the integrant crystal, whose position, after consolidation of the mass, is found coincident with the direction in which the heat wave* has passed out from the mass, if cooling, or into the mass, if heating; and *which direction is necessarily that of least pressure within the mass*, the pressure being that due to distortion or change of form, by contraction or expansion. As matter of observation, this is found to be the longest axis of the crystal in metals, and perhaps in all other crystalline bodies.

But although not ascertainably the optic axis in metallic crystals, future investigation will most probably show, through such transparent bodies as assume in mass the same crystallometric arrangement, that the principal axis, as the term is used by me, has direct relations to the optic axis.

It is certain that it must have immediate relations to the *axes of elasticity* of Fresnel, which again are in direct connexion with the optic axes, as Savart has shown. The relation of these latter, to local or unequal pressure within the mass, have already formed the subject of masterly investigations by Seebeck, Biot, Fresnel, Brewster, and others; and the analogies betweeen the optic effects due to pressure and to change of temperature in transparent solids transmitting polarized light, have been lucidly pointed out by Sir John Herschell, who has well explained that in heating or cooling masses, such internal strains or pressures are produced by expansion or contraction as reduce the proximate cause of the phenomena simply to one of pressure; heat itself having (so far as inferable from those facts) no specific action on the crystalline arrangement, but being merely the means through which internal and unequal pressures are produced. Mitcherlich's facts, long since ascertained, as to the unequal expansion of crystals of certain systems in different axes, even when uniformly heated, indicate unequal elasticity in their respective axes, as well as unequal resistance to the transmission of the heat wave; the latter fact—the inequality of conducting power of crystalline bodies in different axes—is sustained by the researches of Senarmont ("Annal. de Chim.," 3 ser. xxi. 457, xxii. 179, xxviii. 279) in papers of the highest interest. He even found that unequal pressure, in homogeneous uncrystallized solids, altered their conducting power in different directions.

These mutual relations are elucidated in Sir John Herschell's article, Light, "Encyc. Metrop.," vol. iv., secs. 1000, 1085 to 1097, 1113. Such investigations form at this moment the frontier and vantage ground of future conquest, at once in Physics and Chemistry. See also Maxwell's papers on Elasticity, and on Faraday's Lines of Force, "Camb. Phil. Soc. Trans." Dec. 10, 1855.

It has been questioned to me, how far the fundamental fact is established, that iron, in its several conditions of cast-iron, steel, and especially of malleable iron, is truly crystalline at all; whether it may not be possible that the texture of a long, silky-fibred bar of rolled wrought-iron, is due simply to the extension and drawing out, long and fine, of the heterogeneous mixture of amorphous metal, and of included and uniformly distributed "cinder" (i.e., oxides, silicates, and carburets), which might be supposed to form the mass, as first withdrawn from the refinery or "balling furnace;" much like as a mass of bird-lime and dry clay diffused through it, would probably roll or draw out.

I cannot admit the force of the objection, or of the analogy.

All the evidence we possess is in favour of iron having a truly crystalline structure. Such is the structure of all so-called elemental solids, and assumed with distinctness (*cæteris paribus*) in proportion as they approach to chemical purity; not only the analogy here, but that nearer one with the whole class of all other metals, would be broken by such assumption, the crystallizing power being evidenced in all, though developed with very different facility, still in an unbroken chain, from bismuth and antimony, which crystallize so readily, down to whichever may be held most difficult to obtain in crystallized masses. But there is positive evidence of the power of cast-iron, of steel, and of malleable iron to assume the crystalline structure. The form of the integrant crystal is obvious; perfect crystals may be isolated; they possess the property of distinct cleavage in well-developed instances (Wöhler); and the fresh surfaces, often of great size, possess the perfection of plane and of polish, that crystallization can alone confer. Other less broad and obvious characteristics, such as difference of resistance to the action of menstrua in different axes, might be urged. Or again, the difference of elasticity of (chemically the same) iron in different states of development of the crystallization of the whole; and difference of elasticity in different directions in the same mass, following observable differences in the prevailing directions of the crystalline axes.

In a word, there appears no more good reason to doubt the truly crystalline arrangement of the molecules of iron than there would be to doubt that an isolated octohedral crystal of native gold, was truly a crystal, because, by the blow of a hammer, we can flatten it into a spangle. The masking circumstance is alike in both cases. Metallic crystals are all more or less malleable; they are, therefore, susceptible of distortion (to almost any extent, in the more malleable metals), and of re-formation, without external change, except as to form, in the mass itself.

But an additional argument may be drawn from Professor William Thompson's views as to the nature of the forces concerned in thermo-electric currents, from which it would seem to follow that iron, or any other body in which a thermo-electric current can be excited, can have none other but a crystalline arrangement (Thompson, "Dynamic Theory of Heat," Phil. Mag., 1856.)

In addition to the several examples quoted in the text (sects. 9–15), of the arrangement of crystalline axes perpendicular to the bounding planes of the solid, I would remark a very interesting one, given by the late Professor Daniell, "Elem. of Chem. Phil.," sect. 117, p. 88:—If a parallelopiped of tin—hammered or cast, matters not—be placed in mercury for some time, the latter is absorbed gradually: it enters the mass by successive plane *couches*, parallel to its surfaces; expansion is produced in the planes of these couches, and hence lines of least pressure perpendicular to the same. After a time, the parallelopiped is found split up into six pyramids, by planes penetrating from its edges, and intersecting within it,—their bases being the original sides of the solid; and each of these pyramids is found composed of crystals, whose longest axes are arranged perpendicular to the original sides, and parallel to each other; and into these integrant crystals each pyramid may be subdivided.

Here is a case in which chemical change—resulting in the formation of, no doubt, a definite amalgam—has, owing to the peculiar circumstances of its formation in a state of crystalline aggregation, produced an effect similar to that which mere change of temperature might have induced in the parallelopiped of tin, had the latter been originally crystalline, or large enough for internal strains to have so arisen.

Again, the following curious experiment, made by myself several years since, but not previously published:—If a portion of Muntz patent rolled yellow metal (Table xi., No. 12, in text), in the state in which it is used in commerce for ships' sheathing, bolts, &c.—namely, in which it is tough, malleable, extremely flexible, and endowed with a distinct fibrous arrangement in the direction in which it has been laminated or rolled;—if of this a small rod, or a narrow slip, be cut from a sheet, and plunged for a moment or two in a tolerably strong solution of nitrate of mercury, and then withdrawn, washed, and wiped dry,—it will be found that it has almost instantaneously become rigid, and so brittle that it may now be broken into short bits between the fingers, whereas, previously, reiterated bending backwards and forwards, between the hands, would have with difficulty broken it at all.

The surface of the metal is found slightly amalgamated; its fractures present crystalline planes, penetrating the solid in directions perpendicular to its faces; and, on examination of the fracture with a lens, an extremely superficial, but real, penetration of the mercury between the surfaces of the crystals will be observed to have occurred.

The conditions here were different from the former experiment: the phenomena occur with much greater, indeed with truly remarkable rapidity, the transmutation from tough-

ness to brittleness being almost instantaneous; but the results, and their explanation, are the same as in Daniell's experiment.

The chemical change, then, does not prevent this inversion and development of crystalline axis; on the contrary, if it induce the required condition of internal strain, it may produce the same crystalline arrangement that heating, or cooling, or local pressure can do. Nor will the general law, stated in the text, be disturbed by the circumstance of sudden *expansion* taking place in a cooling, and therefore contracting solid, at the instant that it assumes the solid form—as in bismuth, cast-iron, ice, &c.; for expansion here is but the same force as in contraction, changing all the signs; and, however the crystals may be formed in the first instance, they are subject to the subsequent modification in axial direction.

Mineralogy and lithologic geology are full of examples of the play of these crystalline forces under the influence of pressures due to gravity, or to change of temperature; and some of its obscurest phenomena are yet destined to receive light from the application to them of the general law enunciated in the text. What geologist is there who has not observed, that the integrant crystals, forming the mass of quartz and other such veins in igneous rocks, are all arranged in lines perpendicular to the bounding planes of the original fissure—the lines of least pressure in the mass, as it was heated or cooled by the surrounding rock? Upon a greater scale, we find the metamorphic crystals of changed rock, adjacent to dykes of igneous rocks—as in the chalk penetrated by trap in Antrim,—stretching away from the walls of the dyke in lines perpendicular thereto; and the arrangement of the trap, so far as it is truly crystalline at the surfaces of contact, obeying the same law. In Scotland, coal converted naturally into coke, by intrusion of a trap-dyke, assumes the pseudo-crystalline structure known of it, in planes of fracture perpendicular to the bounding planes.

Perhaps even the yet unsolved mystery of the structure of columnar basalt may find its key and solution,—not *in* this law, but by views which it shall suggest; as well as the molecular conditions, upon the physical action of which the lamination and cleavage of the slaty and other rocks of imperfectly homogeneous material has depended, the *directions* of the pressures concerned in which Mr. Sharp and Mr. Sorby have developed with so much ability.

The distinction, however, is to be clearly observed between *internal* pressure inducing change of crystalline axes, in truly crystallizable solid masses, and pseudo-crystalline arrangement, such as cleavage, lamination, &c., produced by pressure *external* to the mass of an uncrystallizable solid, and the indispensable conditions for which seem to be heterogeneity of composition of the mass, and peculiarity of form in its particles. In nature, these latter phenomena may be sometimes mixed up, more or less, with the former, where crystallizable substances are diffused in a mass of uncrystallizable matter.

The navigator in high latitudes has long been familiar with the dreaded fact, that the

thawing iceberg, as it floats upon the ocean into warmer latitudes, often suddenly, and without apparent external cause, or by any that shall produce the slightest vibration, such as the firing of a gun—splits up, and parts asunder into enormous spiriform masses, whose bounding planes are generally nearly, or quite, perpendicular to the surface of the sea, and which fall, and, plunging with fearful commotion, stretch their lengths upon the bosom of the deep. The same law has acted here upon a still vaster scale: the whole berg, reduced nearly to its melting point, has previously received, by conduction from the ocean beneath, and from the air above, its heat in directions mainly vertical, and its splitting planes are so likewise; for the directions of greatest internal strains are, on the whole, horizontal. Its long fragments, if large enough, shall afterwards obey the same law, but in directions now at right angles to that in which it acted upon their parent berg. We may even imitate all these phenomena, upon a small scale, by heating a block of American ice slowly, by one of its flat surfaces, upon a heated plate of metal or of water; or we may observe them in play in the cross or vertical fractures of the thick ice of every pond, as it becomes rotten, and breaks up at the thaw. In the latter case, the vertical crystalline fracture is at the same time aided, and the phenomena are a little perplexed, by the frequent occurrence of numerous minute vertical columns of adjacent air-bubbles in the ice, like parallel chains of microscopic beads, which break the perfect homogeneity of the ice, and whose expansion, by the heat of the sun, may assist in splitting up the ice, as well as produce planes of weakness mechanically within it. (10th May, 1856.)

NOTE F.—(SECT. 18.)

THE figure in Plate II., which indicates the direction of fracture, in the base of the cylinder, of the Britannia Bridge hydraulic press, is a little erroneous in direction (as I am informed by a friend who had opportunity of examining the original, which I had not). The fracture, striking outwards from the neighbourhood of the internal angle, made by the base with the sides of the cylinder, passed outwards (as in the figure), at first nearly at 45° to the line of the sides, but gradually curved upwards, and cut through the outer surface of the cylinder, in some places, round the circumference, rather above, than through, the external salient angle, formed by the meeting of the exterior of the base with the sides; thus departing towards the outside more or less from the " plane of weakness." At first sight this appears to militate against the views of the text, as to the existence here of such a plane of weakness, as, wherever was the weakest plane, the fracture should have followed it quite through; but a more careful consideration of the question, than was given by me while engaged upon the text, will show that the facts, thus corrected, point the opposite way, and perfectly sustain the views advanced. The fracture was a

diagonal one, tending generally from the internal angle outwards; but if there were no plane of weakness here at all,—if the metal were of the same cohesion per square inch throughout all its parts,—the weakest place must have been that of *least section of metal* in the directions exposed to pressure; and as this is in a plane at right angles to the axis of the cylinder, the sides of the latter would in such case have been torn directly across somewhere; the cross section of fracture then being less in total area, than in case of a fracture from the internal to the external angle at the cylinder's base, in the ratio of $1 : \sqrt{2}$.

The diagonal must therefore have been the weakest place—Why did it not break straight through it? The reason is obvious, when we come to consider the nature of the fluid forces to which it was exposed before fracture.

The normal or radial pressures against the interior of the curved sides of the cylinder, and against the base at right angles to itself and to the former, *commenced* a rent at the interior angle,—a certain amount of *flexure*, however small, being produced in the metals at both sides of it. This flexure, however slight and instantaneous, had necessarily the same effect as if the fracture took place by rotation round consecutive points whose *loci* were in circles all round the outer edge of the progressive fracture; and as the greater *motion* was in the base which was projected off, so the fracture curved upwards, just as the fracture described in burst guns turns off to one side, very near the outer surface.

The irregularity of broken surfaces, and of the line of rupture, with reference to a plane parallel to the base, was, no doubt, due to irregularities in the casting itself, or other accidental conditions.

NOTE G.—(SECT. 25.)

EXPERIMENTS, of the same character as those of Mr. Fairbairn, have been made in the United States, upon the larger scale of casting guns, at various periods, for several years back, some of which are detailed in a collection of Reports by officers of the American Ordnance, published this year (Trübner, London), and which has met my eye, for the first time, while these sheets are passing through the press (May, 1856). These experiments on the effects of remelting, or of prolonged continuance in fusion, are of the same inconclusive character; and the few deductions made are sometimes anomalous and inconsistent. It is impossible to avoid observing, that none of the experiments appear to have been devised with any preliminary guiding theory, based on just or sufficient chemical and metallurgic knowledge.

What, then, do such experiments on remelting of cast-iron amount to?

It has been well known for probably a century, that white cast-iron (No. 4 pig) has a far higher ultimate cohesion than any of the gray, mottled, or dark gray varieties (Nos. 1, 2, and 3, pig). It has been known, for nearly the same period, that the latter may be con-

verted more or less perfectly into the former, by repeated fusion in direct contact with fuel and blast; and it has been equally well known that either white or gray iron may be obtained at will, and by a first or single fusion, from the smelting furnace.

For nearly thirty-five years, the nature of these changes has been fully understood, through the researches of Karsten, by whom it was proved that gray cast-iron (Nos. 1, 2, 3) contained carbon in two states, chemically combined and mechanically diffused, the latter as crystals or scales of graphite; and that white cast-iron (No. 4) contained carbon in but one, viz., wholly in combination with the iron,—the extreme case being that of the Spiegeleisen (Fig. 3, Plate v.), in immense, well-defined crystals, which contain above 5 per cent. of combined carbon,—somewhat less being found in Fig. 6, the more usual fracture of lamellar (No. 4, white pig-iron); becoming mixed with uncombined carbon, as graphite, in the mottled iron (Fig. 7); and having its largest proportion of diffused graphite in very dark gray (No. 1, pig), possessing fractures more or less resembling Fig. 5.

Karsten proved, that any one of these varieties of cast-iron could be converted by suitable metallurgic treatment into any other, and that, as respects the conversion of gray cast-iron into white, the process was, to a greater or less extent, the inevitable result of every time the gray metal was melted and cooled,—that it was dependent simply on two conditions:—

1°. The deprivation of graphite *in the furnace*, due to the proportion that should be given to air-blast and fuel.

2°. To the fact that in the act of consolidation a certain proportion of the whole of the suspended graphite was *exuded*, i. e. forced out to the surface of the cooling mass, by the crystallization of the whiter portions, whose carbon is combined.

Now, it follows as matter of course from these well-known facts, that, as perfectly white cast-iron has at once the highest cohesion and the greatest brittleness, while properties the reverse belong to the darkest gray graphitic cast-iron,—some mixture of the two *qualities* (*not of the two irons*) must give the best material for gun-founding, or for any other mechanical purpose, in which the highest product of tenacity and toughness is demanded. And in this consists the value of " mottled iron" (Fig. 7, Plate v.) for cannon.

It also is obvious, that a more or less perfect approach to such a mixture may be made by repeated melting and cooling, up to a certain point, of any gray iron; but the number of meltings and coolings necessary to effect this will differ, not only with the original gray iron tried, but with the conditions of the cupola furnace in every consecutive melting, and with the conditions of cooling at every casting, so that probably no two series of experiments could be possibly made, that should give co-ordinate results, or that would be applicable to any other make of iron, or to any other cupola, fuel, and blast. Moreover, the quantity of graphite eliminated at each cooling is greater, in some proportion, as the cooling is more rapid. The trial, therefore, that shall give the number of meltings producing the

best result for castings of one dimension cannot be true or applicable to castings of any greater or less scantling.

Thus, if, as Mr. Fairbairn concludes, the thirteenth melting gives the best metal, for trial bars cast one inch square, with the original "make" of pig-iron, and mode of melting and casting, he employed,—it does not follow that for bars of two inches square it would be so; or that, with the one-inch bars, but a different original "make" of pig-iron, or a different cupola, it would be so; or even with the same pig-iron and conditions of melting, but a different mode of moulding and casting the same one-inch square bars, the result should be alike. If, with the very same pig-iron, cupola, and fuel, the meltings be performed with a surcharge of metal and flux in proportion to fuel, and an excess of blast, the one-inch square bars, when cast, would have been found to have arrived at their assumed best quality, perhaps, at the fourth, in place of the thirteenth, melting. If the bars themselves had been cast in "chills," in place of sand-moulds, so as to have been cooled as fast as possible, the point would have been still sooner reached, and, if cast in "dry sand-moulds," or "in loam," would have been later reached.

Upon sample bars so small as one inch square, even a *little more or less wetting of the sand* of the greensand-mould, on the part of the moulder, would have made the most formidable difference as to the rate of progress towards white iron. Finally, if, instead of bars of an inch square, the experiments had been made upon a sufficient scale to admit of casting bars of a foot square, these, when broken after the thirteenth melting, in place of presenting the same assumed improvement, would in the interior have presented very little change in fracture from the original pig-iron (unless, indeed, peculiar care had been taken to so work the cupola as to burn out in it the graphites—a thing most difficult to accomplish at all upon a large scale, and not in question here); and in place of the thirteenth melting being the charmed one, it might not be reached at the 13×13th melting.

The conclusion drawn by Mr. Fairbairn is, therefore, too large, is not warranted by a just interpretation of the premises, and might lead to serious mistakes in practice; for, as has been shown in the text, this same best quality of iron, this same combination of strength and toughness, can be obtained direct from the ore in the blast furnace, and either run into pigs, or, far better, cast into guns or other large objects requiring it, at once, and without any intermediate cooling. The whole roundabout process of repeated melting is, therefore, perfectly needless—but, further, it is positively hurtful; for, every time cast-iron is melted in contact with fuel and flux, it takes up a fresh additional dose of the metallic bases of the alkalies and earths; and it is to the alloy of these, especially of the latter, that a more fatal reduction of strength and toughness is due, than to any other foreign mixture with which cast-iron is known to combine—so that, by this notion of repeated meltings, we spoil the pig-iron in trying to effect, by an indirect process, what, with better knowledge, should be the direct result of the primary and single operation of the smelting furnace.

The American experiments, upon the possible improving effects of keeping the metal for a longer or a shorter time in fusion in the furnace, although too few and inconclusive as to condition, to infer much from in any way, are only an analogous case. The longer the metal remains in the furnace, exposed to contact, at a high temperature, with many foreign materials (the fuel, the flux, and the furnace itself), all highly heated, the greater will be the dose of alkaline and earthy metals it will have taken up by cementation, and become alloyed with—although possibly, at the same time, a certain amount of approach towards mottled iron may have occurred; and hence, in that respect, some improvement. But, that the general effect is one of deterioration, is well known to practical gun-founders, wherever the guns are run directly from the blast furnace, who are well aware, by long experience, that the metal tapped from very near, but not quite at, the top of the fluid mass in the furnace, and which they call " the cream" (Rahm), produces the best gun castings. Now, this is just the portion of metal, of the whole that the furnace contains, that has been the least exposed to the deteriorating influence, of continuing in fusion, and is almost that which has been the shortest time melted.

Note H.—(Sect. 29.)

Zinc, as found purest in commerce, and cast in the ordinary way, is malleable and laminable, within a range of temperature of about from 200° to 350° Fahr. If this range be extended by the change in molecular arrangement due to the circumstances alluded to in the text, analogy would induce the expectation, that the range of extensibility to tensile and compressive forces, in cast-iron, would be likewise extended by similar treatment, viz., by " pouring" at the lowest possible temperature.

Note H, *bis*.—(Sect. 59.)

It is worthy of remark, that in the case of the burst Cavalli gun at Woolwich (Proof Department) which was cast at Äker in Sweden, the fracture presents a coarse, granitic, and soft aspect, indicative of a weak quality of metal, little better than that of the split Baltic mortars. It is obvious, therefore, that neither "cold blast," nor the absence of coal fuel, will alone insure proper metal for guns.

The conditions of physical structure in cast-iron, developed in the fourth and fifth chapters, derive an unconscious confirmation from a remark made, with much accuracy of observation, by Mr. Edwin Clarke (" Description of Britannia Bridge," vol. i. p. 380), in which he states that the central crystals, in a large mass of cast-iron, are larger than those nearer the surface, which he, however, attributes to a not very clearly made-out effect of the prior consolidation of the exterior of the casting. In alluding, further on, to Lieut., now

Major James's, R.E., experiments on this subject, he briefly quotes his important result, also confirmatory of the views of the text,—that equal sections, cut from the interior of large castings, are weaker than from portions nearer the surface (vol. i. p. 443).

The true reason that the central parts of the mass present the largest crystals, is because, having been the *longest hot*, these crystals had *most time given them for large and perfect development*, and the centre is the weakest part of the bar, not only because these parts are rendered porous and of low specific gravity, by the drawing asunder produced by the prior consolidation of the external crust, but also because the force of cohesion between the planes of cleavage of the largest developed crystals is the final measure of the strength of this, the weakest, as they are of every other part, in proportion to their development.

NOTE I.—(SECTS. 43 TO 50.)

SINCE the text has been written, a number of 13-inch sea-service mortars have been brought home disabled from the Baltic, having failed on board the mortar boats, during the bombardment of Sweaborg, after a greater or less number of rounds, in a very remarkable way,—the conditions of which do not appear as yet to be accounted for by the Departments at Woolwich. (March, 1856.)

I examined these mortars (15th Dec., 1855) in the Arsenal, with much care and interest, and advert to them here, as affording the most convincing proofs of the truth of the views I had advanced as to the causes affecting the bursting of ordnance; and I am enabled, by the application of my views to the case, to explain completely the conditions and circumstances that have produced the particular form of failure exhibited by these Baltic mortars.

Of the whole number of mortars, three have burst, or, to speak more correctly, *split*,—the remainder still appear to hold together,—but the strong probability is, that there is not a serviceable or trustworthy mortar remaining amongst them.

List of 13-Inch Sea Mortars, and Names of Mortar Boats, with Number of Rounds fired, and result.

	No. of Rounds.	Cast at	
Pickle, ...	114	Low Moor.	Split.
Growler, ...	355	Carron.	,,
Mastiff, ...	148	Carron.	,,

Each of these three mortars was split with almost perfect exactness into equal halves, by

a plane passing through the axis, and through the centre of the vent. There were no signs of unsoundness in the metal at any point, nor any defect or sign of injury, other than the splitting up, save that at the centre of the bottom of each chamber, a small, irregular cavity was formed, with jagged sides and bottom, as though slowly burrowed into by some corroding agent.

The fractured surfaces, where rusty, presented an uniform, very coarse-grained character of metal; and where the latter was freshly exposed by a large fragment recently cut out, close to the interior at the muzzle of each split mortar, it proved to be a mixed metal of the very coarsest grain, consisting of nearly white cast-iron, filled with large grains of very dark gray and highly graphitic iron, greatly wanting in homogeneity (fonte fortement truitée), a material ill suited to ordnance of any sort. Its general appearance was somewhat that of Fig. 5, Plate v., but much coarser.

The following mortars remained together, but in what condition I was unable to judge.

	No. of Rounds.	Cast at
Havock, ...	94	Carron.
Rocket, ...	241	Low Moor.
Beacon, ...	176	Carron.
Surly, ...	131	„
Grappler, ...	311	„
Porpoise, ...	213	„
Prompt, ...	184	Low Moor.
Drake, ...	129	„
Manly, ...	277	Carron.
Blazer, ...	287	„

These mortars have split, I apprehend, from the conjoint effect of three separate causes:—

1°. The metal is of bad quality,—coarse, heterogeneous, and, most probably, of low specific gravity and small elastic range.

2°. A certain amount of that condensation of the material at the interior of the bore, which takes place at every discharge, in every piece of ordnance, and gradually disables it, has, probably, taken place here; but—

3°. The mortars very rapidly fired in a cold climate, have had their interiors powerfully heated, and expanded thereby, while their exteriors have been kept almost cold, by the heat carried off by "evection" of the surrounding currents of air, in the way described in the text (chaps. 9–17). The large diameter and great thickness of these mortars (one caliber) has exaggerated this effect, and the splitting has taken place in a plane passing through the vent, because the splitting tension of the unequally expanded interior and exterior will be greatest, where the difference in temperature between the interior and exterior

at any point round the circumference is greatest; but this, in a mortar inclined about 45°, will be at the lines cut by a vertical plane passing through the axis,—because the whole interior may be assumed heated equally all round; but, of the exterior circumference, the lower side, that opposite the vent, is most cooled, because against this side of the warmed mortar the ascending currents of air impinge, and most completely evect the heat from it;—while at the opposite, or top side, the heat is least evected: the splitting tension is greatest, therefore, in the plane through which these three mortars have been split. Besides this, on the principles of molecular aggregation of castings, previously explained, the mass of the trunnions at either side produces *a plane of relative weakness* towards the base of the mortar, just where fracture has occurred; and lastly, the section through the vent is the weakest of any one passing through the axis, that the mortar presents, because the least total section of metal.

The excavating that has taken place at the bottom of the chambers is easily accounted for. The metal—coarse, uneven, and open-grained throughout—was at this point, from causes pointed out (sect. 45 of text), a spongy mass of scarcely coherent crystals, with scales of uncombined graphite mixed with them and interposed; the latter in the first instance, and the plumose crystals of cast-iron (iron and combined carbon) afterwards, exposed to the intense heat and flame of the ignited powder, are themselves set on fire, and gradually deflagrated; and so, bit by bit, the irregular little cavern was *burned out*, just where the central "soft spot" in the casting existed. It is a case precisely analogous to the enlargement of vent and of chase near the seat of the shot, so commonly observed in guns.

The remedy for all these evils is not difficult, and was, in fact, pointed out by me in a communication as to a new form of mortar, made to Government early in 1855, but put aside on grounds that only proved that it had been set aside unconsidered, or the want of information, on the part of the examining authorities, to enable them to judge such questions, which demand, not "artillery practice," but a clear and accurate knowledge of many, and some not very obvious, physical and mechanical truths, and the power practically to apply them. I recommended that mortars should be increased in length of chase; the thickness of metal reduced; made perfectly uniform all round, and proportioned to the internal pressure at every point,—i. e. tapering to the muzzle; to abandon all trunnions (as weakening the piece); and to receive the recoil directly from a flat breech, by an elastic, and simple but peculiar bed; and to cast all mortars hollow, on well-formed "cores," without subsequently boring them out at all,—thus not only saving greatly in first cost, but avoiding, as respects the molecular arrangement of the material, all the evils resulting from the existing cumbrous and absurd forms, so that the form recommended would have approached,

but been better than that of, the French howitzer, or mortar, taken at Cadiz, and now in St. James's Park,—an instrument well designed, by obviously competent men, and which, though made under difficulties, and of inferior material, answered its intended object.

It would have been of much interest and value, to have been able to corroborate the truth of the views I have here advanced, as to the causes of the failure of these Baltic mortars, by a few experiments on their metal. With this view I applied for a portion of each split one (a pair of bars, together not more than 5 lbs. or 6 lbs. weight), and stated my views and object; but was refused by the Ordnance Select Committee, at Woolwich, on the ground that they wanted the mortars (*fifteen tons* weight of metal!) for their own experiments. A second application, received for answer, that *after* the Committee should have reported on its own experiments, it would *consider* my application!

Months have since elapsed, but I have never heard further as to my application; I have learned, however, that experiments, similar to those which I indicated, and requested the means of making, have been since performed.

In concluding this Note I may mention, that an officer stationed in the Baltic informed me, that these mortars were fired for some time, as fast as they could be loaded,—perhaps at the rate of twelve shells per hour, or more. Possibly the success of the bombardment demanded great rapidity of fire: but the French mortar-boats, having two mortars on board, which can be fired alternately, possess an advantage over ours with but one.

A heated mortar will be most safely and readily cooled by filling it up to the brim with cold water, as rapidly poured in as possible. The water may be easily taken out with a gutta-percha syphon, and the interior dried with a swab.

The method and mixture of cast-iron, described in sect. 59, is that still actually in use in foundries employed casting ordnance by contract for Government, and is just the material of which the Baltic mortars consisted; the grain of the metal of those split was as coarse as granite.

One of these was cast at Carron, perhaps more than forty years ago; so the malpractice is an old one, and its evil results have nothing to do with "hot-blast."

Imagined Causes of Inferiority and Superiority in various Cast-Irons.

It is stated in the "Report of the Commission of Inquiry," p. 17, as to the manufacture of ordnance on the Continent, which has appeared while those sheets have been passing through the press, on the authority of Schür and Mitscherlich, that in Swedish iron works, pyrites (sulphuret of iron) is thrown into the furnace, with the other constituents of the charge, to produce the fine, gray, mottled iron required for gun-founding; and it is added, that the effect may be analogous to that of the oxidizing flame in a reverberatory furnace,—some doubt being at the same time expressed as to the accuracy of the reported

fact. The fact itself has long been known in the iron works of northern Europe, that pyrites, in the blast furnace, will produce white iron, or an approach to it; and, possibly, it has been occasionally resorted to with the intention of producing this end. The rationale of the process, however, is not that suggested by the reporters, but has been fully developed by Janoyer, "Ann. des Mines.," 4 ser. t. xx. p. 359, and elsewhere, who has shown that sulphur and carbon mutually eliminate each other, by combining in the blast furnace, and becoming volatilized, as sulphuret of carbon. But, although this be chemically true, and a fortunate condition in always aiding in the expulsion of sulphur from crude iron, no prudent iron-master would dream of voluntarily resorting to such a method of obtaining mottled iron as this, inasmuch as no care or skill in the working of the blast furnace could insure, for an hour together, the production of pig-iron, that should not contain an excess of sulphur. The method, too (as is obvious from the text) is as needless as it would be perilous to the quality of the product.

Sulphur, in the state of sulphates, or other saline combinations, cannot but be introduced into the blast furnace, whether we use our own raw coal, washed coal as in Belgium, by which a material reduction of impurity is obtained, coke, anthracite, or even wood, in whose ashes sulphur is not absent, any more than in the majority of the limestones used as flux. Berthier and others have clearly shown, that the amount of sulphur finally included in the yield of iron, is not in proportion to the sulphur contained in the fuel or flux, but depends upon a multitude of conditions in the working of the furnace, and chiefly upon the proportion of lime in the flux, and on the temperature of the furnace; but, that a sensible improvement in the quality of the pig-iron has been obtained in Belgium, by washing the coal, so as to oxidize the contained pyrites into copperas (sulphates), and thus remove it in solution, appears certain; and the marked differences noticed between irons, made with coal which contained sulphur in the proportions of 0·28 per cent. and of 0·64 per cent., in favour of the former (Janoyer), indicate that the washing process, *extended* to *coke*, and given sufficient time, would, in Great Britain, be attended with the best effects as respects the production of iron for gun-founding. Coal fuel is much deteriorated in heating and "bearing" power by washing; but not so coke, which may be exposed to air and water (if frost do not supervene), for a length of time, without injury to it as fuel.

A most important contribution to our knowledge of all that relates to the iron industry of Belgium and France, worthy of being better known in English, has been made by the "Reports upon the Condition and State of the Iron Manufactures of Belgium and of France," by M. Hector Rigaud, Eng. Civ. des Mines. (Ann. des Mines, 4 ser. t. viii. p. 371, &c.)

It is by no means certain, however, to what extent, or if at all, the presence of minute proportions of sulphur reduces either the tenacity, or the toughness, of cast-iron of given quality in other respects; certain it is, that these depend more, nay, primarily, upon the proportion and molecular condition of the carbon it contains, and that the alloy of small

portions of the alkaline and earthy metals produce a greater deterioration in those qualities than any other foreign additions. The presence of these last is the peculiar characteristic of hot-blast iron, arising simply from the extreme elevation of temperature of the furnace.

How little the proportion of sulphur depends alone upon fuel, &c., and how nearly it is alike, or may become so, with any fuel, may be seen from the following analyses of American cast and wrought-iron, made by M. Svanberg ("Jour. fur Prac. Chem." h. xl., p. 232):—

American Cast-Irons.

	a	*b*	*c*	*d*	*e*	*f*
Carbon, ...	2·8913	2·3909	3·0529	5·3617	6·4797	4·4064
Silicium, ...	0·8293	1·9042	1·3442	1·0948	1·9607	1·0350
Aluminium, ...	. . .	. . .	. . .	. . .	. . .	0·0406
Calcium, ...	. . .	. . .	. . .	. . .	. . .	0·0163
Phosphorus, . . .	0·1592	0·0272	0·1224	0·1806	1·4591	0·0017
Sulphur, ...	0·0052	0·0044	0·0028	0·0170	0·0023	0·0600
Copper, ...	. . .	. . .	0·0101	0·0235	. . .	0·0154
Iron, ...	96·1150	95·6733	95·4676	93·3224	90·0985	94·3948

a, From Juanitá; *b*, from Longmine, Orange County, New York State; *c*, Salisbury iron (that of which the Princeton gun is stated to have been forged), Connecticut; *d*, Missouri; *e*, Anthracite iron of Columbia, Denville County; *f*, Iron of the Le High Company:—

American Wrought-Irons.

	a	*b*	*c*	*d*	*e*
Silicium, ...	0·3765	0·5323	0·0876	0·2870	0·3006
Phosphorus, . . .	0·0942	0·0283	0·0235	0·0295	0·0773
Sulphur, ...	0·0042	0·0010	0·0055	0·0024	0·0020
Copper, ...	0·0168	. . .	. . .	. . .	0·5544
Iron, including Carbon and loss, . .	99·5083	99·4434	99·8833	99·6811	99·0657

It is much to be regretted that these latter analyses give the carbon only by the loss. *a*, Is Juanitá iron; *b*, Longmine; *c*, Salisbury; *d*, Missouri; *e*, Nail-rods, or slit-bars. The relative strengths of several of these makes of iron are given in the Table, section 210, text.

In comparing these Tables of tenacity of American irons, and more especially the results given in the volume of "United States Ordnance Reports," recently published by Trübner, London, with the admitted standards of tenacity of British irons, mainly due to the laborious, valuable, and almost life-long researches of Hodgkinson,—this must be distinctly borne in mind—that the American experiments are made chiefly upon mottled gray iron, carefully prepared, as the toughest and most tenacious procurable by *mixture or*

by smelting, specially for gun-founding; while all the experiments made on British irons, with a very few exceptions (see E. Clarke, "Brit. Bridge," vol. i., p. 445), have been made upon *specimens of unmixed commercial pig-iron,* as found in the market, intended for the common purposes to which cast-iron is applied, and not having that peculiar balance, of hardness, tenacity, and toughness, indispensable for gun-metal, but unsuitable to the purposes for which our mercantile "makes" are intended, and incapable of being afforded at the price at which these are sold. It really would appear, however, from much that has latterly been written and spoken on the subject, and even by those whose authority and position would presume better knowledge of the subject, that these facts have been overlooked.

As proving how completely the per-centage of sulphur, as well as of all other impurities, depends upon the working of the furnace, the following Analyses, by Dr. Schafheautl ("Revue Scien." t. xxv., p. 192, and t. vi., p. 209), are important, *all made from iron produced by the same furnace, and in continuous blast*—that of Alais, Dep. du Gard, France, the specimens being taken at successive periods:—

Per-centage of Foreign Constituents only.

Silicium, ...	1·860	2·006	0·483	2·978	0·502
Aluminium, ...	0·108	0·098	0·013	0·088	
Carbon, ...	5·800	4·750	2·750	4·269	1·428
Azote, ...	0·874	0·585	1·036	0·639	0·183
Sulphur, ...	0·645	0·800	0·380	0·433	1·003
Arsenic, ...	0·050	2·560	4·080	3·840	0·934

And as enabling a comparison to be made of the relative effects of cold and hot-blast in the same blast furnaces, and these, too, worked with *wood fuel only,* the following analyses of hot and cold-blast irons, made at Königshutte and Leerbach, in Hanover:—

	KÖNIGSHUTTE.		LEERBACH.	
	Cold Blast.	Hot Blast 200° Reau.	Cold Blast.	Hot Blast 160° Reau.
Graphite, ...	1·99	2·71	3·85	3·48
Carbon combined, ...	2·78	1·44	0·48	0·95
Total Carbon, . .	4·77	4·15	4·33	4·43
Silicium, ...	0·71	3·21	0·79	1·91
Aluminium, ... } Calcium, ... Magnesium, ... Manganese, ... Sulphur, ... }	Traces of all of these in every case.			
Phosphorus, ...	1·23	1·22	1·22	1·68
Total foreign bodies, . .	6.23	8·53	6·34	8·02
Specific gravity, ...	7·430	7·166	7·081	7·077

FIG. 1.

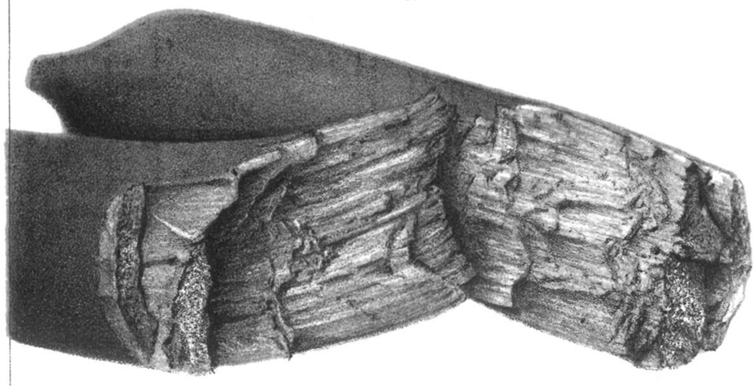


FIG. 2.

FIG. 3.

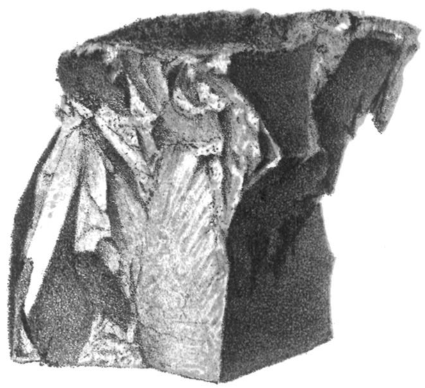


FIG. 4.

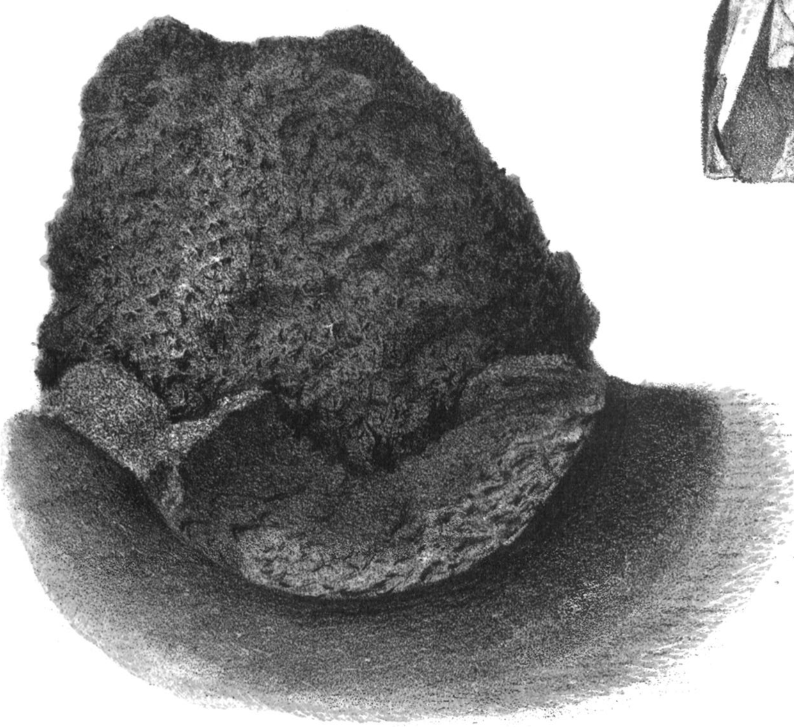


FIG. 5.

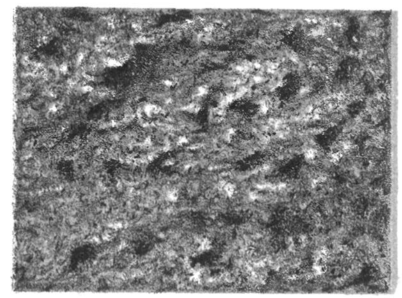


FIG. 6.

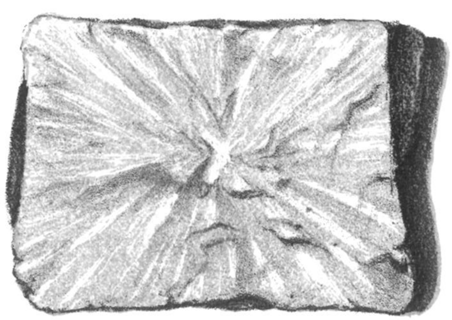
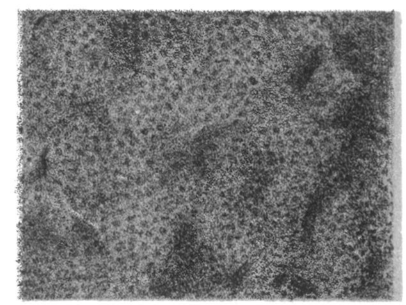


FIG. 7.



The furnace of Königshutte is fed with beech; that of Leerbach with fir fuel.

The analyses are by Bodemann ("Pogg. Anal." t. lv., p. 485). Sulphur was present in every instance; and had the amount of the earthy and alkaline metals admitted of estimation, they would have shown, doubtless, some preponderance in the case of hot-blast with wood as with coal fuel, from the higher temperature of the furnace.

The molecular condition of the carbon in the pig-iron—the proportion in which it is developed as graphite, and in which it is in combination chemically with the iron—seem also much dependent upon temperature, as well as the magnitude of the individual crystalline scales of graphite, *upon which, more than upon any other condition, the tenacity of cast-iron appears to depend; it being obvious that in mixed irons,* constituted like the coarse masses of which some of the Baltic mortars, referred to in a previous Note, consisted, *the strength of any given section is limited to the strength of that portion of the whole reticulation which is solid iron, since the nests of crystalline graphite are almost devoid of cohesive resistance, and may be absolutely deducted,* quoad *ultimate tensile strength.*

Upon this part of the subject the following authors or papers may be consulted with advantage:—Karsten ("Ann. der Chem. und Pharm.," lx., p. 230), on the "Constitution of the Spiegeleisen," in which the whole of the carbon is in combination, and which contains from 4·28 up to the enormous proportion of 5·723 per cent. of carbon; its colour bright and silvery, with intense hardness, and breaking into huge, fully developed rhomboidal crystals, often two or three inches long, as figured in Plate v., Fig. 3, text.

Berzelius "On the Allotropic Modifications of the Simple Bodies." ("Jahresbericht," 1844, p. 18.)

Sandberger "On Carbon developed in large hexagonal Tables in the Slags of the Iron Work of Dillenberg, Nassau." (Liebig & Kopp, "Jahresbericht," 1851, p. 151.)

Schafheautl, various papers in "Phil. Maga.," London; and "Pogg. Ann." on same subject.

Laurent, "Ann. de Chim.," t. lxv., p. 417.

Le Play, "Mem. on the Manufacture of Steel," "Ann. des Mines," tt. iii. & ix. 4ie ser.

Engelhardt, "On Tubercular Masses of Carbon, formed (apparently from a volatile state) within the Masonry of the Blast Furnace of Niederbronn, Lower Rhine." ("Ann. des Mines," 4 ser., t. iv., p. 429.)

PLATE V. (next page) is inserted out of its proper place, not having been received from the lithographer in time, in consequence of unavoidable delays in procuring the specimens and taking photographs of them, from both of which the very faithful figures of the Plate have been prepared.

The Plate illustrates the principal states of molecular condition, in which cast-iron and wrought-iron respectively are found; as in every mineral substance, nothing but actual observation of specimens can give complete or accurate knowledge of either the aspect or properties of iron. To those less practically conversant with the subject, these figures will, however, afford the means of understanding more fully the text, and give a clue to the identification of the several molecular conditions of iron when actually met with.

The figures bear reference to the subjects discussed in Chaps. 3, 4, 5, 6, 7, 22, 23, 24, 25, and 26 of the text, and in this and other Notes.

Figs. 3, 4, 5, 6, and 7, relate to cast-iron. Figs. 1 and 2, to wrought or malleable iron. They are all drawn to one-half (linear) the natural size.

Fig. 3 represents a fragment broken off from a refinery pig, of Styrian cast-iron (Spiegeleisen), the top of the figure being the upper side of the flat slab, of about 4 in. thick, 18 in. wide, and some feet in length, when cast; and the lower side of the figure, the bottom of the pig, which is usually cast in iron or "chill" moulds, and cooled also by affusion of water, when intended for conversion into wrought-iron afterwards; hence called "Refinery Pig."

This may be considered as the normal type of cast-iron—consisting of iron with frequently above 5 per cent. of carbon, the whole of which is in chemical combination with the iron, which hence contains no graphite. The mass is, therefore, perfectly homogeneous in constitution; is of a bright silvery-white colour; the fracture proves it highly crystalline, the crystals being very large and perfectly defined, often some inches long, cleaving with perfect faces and angles, and the hardness so great that a cast-steel file with difficulty abrades the mass.

It will be remarked, that the principal axes of the crystals are all approximately perpendicular to the top and bottom of the slab, i.e. to its cooling surfaces, in accordance with the general law. All "chilled" cast-iron approaches more or less to this normal type.

Fig. 6 is a pig of Acadian or Nova Scotia cast-iron, presenting the usual characteristics of that form of pig-iron known in Great Britain as No. 4 pig. It is closely allied in chemical constitution to the preceding, but usually contains more or less uncombined carbon, in the state of minutely diffused graphite, not visible to the naked eye, but communicating a slight dulness or grayish shade to its otherwise silvery lustre. Although the fracture drawn here is nearly square, the general form of the pig was irregularly roundish, or cylindric, with one flattish side—hence the principal axes of the crystals radiate from a central point, in accordance with the general law. The crystalline structure of No. 4 pig is never very perfectly developed; it is usually more or less lamellar in fracture, sometimes almost perfectly uniform or glassy in fracture, and, except for refining into bar-iron, or mixing with more graphitic cast-irons, is useless to the founder, being brittle and intensely hard when cold, requiring the highest temperature of all cast-iron for fusion, and

remaining at temperatures, however elevated, pasty and viscid. It contains less total carbon than the preceding, and is, in fact, an approach to imperfectly developed wrought-iron.

Fig. 5, a portion of a large pig of No. 1 Scottish cast-iron; soft, very dark gray in colour, very fusible, containing a very large proportion of uncombined carbon in the state of suspended graphite, diffused in scaly or micaceous crystals throughout the mass, upon which it confers its peculiar form of large, pretty uniform, but irregular and ill-developed crystallization, with its dark gray metallic lustre relieved here and there by light reflected from the flat faces of spangle-like crystals, some of which often can be separated, and blown away from the surface. This is the other extreme end of the series of cast-irons; the most fusible and liquid when melted—the least rigid and tenacious, and the softest when cold.

Cast-irons, produced directly in the blast furnace, with properties intermediate between Fig. 6 and Fig. 5, and passing by insensible degrees from one to the other, or produced by mixture in fusion of the two, constitute the vast mass of the castings of commerce for all purposes, and the pig-irons known as Nos. 2 and 3; and of these mixtures, cannon, &c., are frequently cast. But—

Fig. 7 represents a portion of the fractured surface of a mass of "finely mottled cast-iron," of the proper texture and quality for casting ordnance, as obtained directly from the smelting or blast furnace, and at once run into guns. If run into pigs, and again melted for guns, it approaches in the process either towards No. 6 or No. 5.

This mottled iron *may be imitated* by mixing Nos. 6 and 5, with more or less success, in proportion to the skill and tentative knowledge of the founder, and the qualities of the pig-irons employed; but *the physical properties of the cast-iron so produced are totally different from those of mottled iron prepared in the smelting process, by which, alone, fineness of mottle can be insured.* The *fineness* suited to guns is shown in the figure, to natural size.

Fig. 4 represents the form of development of crystals in octohedrons, frequently found lining the walls of "draws," or other internal cavities in castings of iron. That figured was in fine mottled iron. The subject is referred to in Chaps. 5 and 6 of text.

Figs. 1 and 2 represent the two normal extremes of molecular structure of wrought-iron of good quality.

Fig. 2 is a fragment fractured from *a large mass of forged* or steam-hammered iron: it consists of large crystals; some, in the specimen drawn, as large in surface as a fourpenny piece, with distinct cleavage in planes, generally perpendicular to the cooling surfaces or contour of the mass, and, therefore, generally parallel to planes of fracture.

Fig. 1 is a portion of a round bar, of 2 inches diameter, *rolled* out of iron identically the same in quality with Fig. 2, the bar being "nicked" on one side, and then broken and bent back by blows to the form figured. Its structure consists of perfectly uniform, straight fibre, or crystals, all parallel to the axis of the cylindric bar. This is the other normal extreme.

No. 2 can be transmuted to the structure of No. 1 by rolling simply, without any other change, and *vice versâ,* No. 1 may be transformed to the crystalline and comparatively brittle and uneven structure of No. 2, by welding and forging together the most tough and perfectly fibrous bars, *provided the mass be large.* See Chaps. 22 to 26 of text.

NOTE K.—(SECT. 89.)

THIS may be put under another form:—If the tension due to the integral or sum of all the partial strains of the exterior of the gun exposed to tension by the variable strain of the expanded interior $= \beta$; $2\pi R =$ the length, R being the radius corresponding to β, and $l =$ the extension sustained between t and t', then $T = \beta\varepsilon \frac{l}{2\pi R}$, and if ϱ be the coefficient of rupture due to the material. Rupture will occur when

$$\beta\varrho = \beta\varepsilon \frac{l}{2\pi R},$$

or, to prevent it, β must exceed

$$\varrho - \frac{l}{\varepsilon 2\pi R}.$$

A consideration of these conditions, along with those developed in the latter chapters of the text, will indicate the inutility of construction of guns or mortars of cast-iron of considerable thickness, and reinforced with a single ply of heavy wrought-iron hoops, shrunk-on hot, or driven on upon a conic exterior, as originally proposed by M. Thierry, Cap. d'Artil. (" Applic. du Fer au Construc. d'Artillerie," tom. i., p. 153, Paris, 1834), and since attempted in various forms in England, one of the latest being a proposition to strengthen (?) the 13-inch sea-mortar, of *one caliber thick,* by one ply of about 3 inches thick of such wrought-iron hoops outside. In all such cases, from the great thickness and rigidity of the interior cylinder of cast-iron, the latter is strained to its utmost limits and split, before any effectual support can be derived from the exterior hoops. They are, therefore, useless in any case, except when, as in the construction proposed in the text, the mutual relations of the interior and exterior of the compound gun, are such as to equalize and make perfectly isochronous the strain upon both. It must be distinctly understood, however, that the constructive references and figures in the text of the subsequent chapter, headed, "Proper Construction of Wrought-Iron Guns of the largest class," are not to be viewed as more than indications of the *principles* of design proposed, and not as conveying detailed instructions as to the practical methods of carrying such out, for which special designs and specifications, fitted to the particular case, would be demanded. I state this, to avoid the possibility of a cavil being raised on any point of practical detail of structure, where none are meant to be given.

Mr. James C. Maxwell, in a very able paper, in "Trans. Roy. Soc., Edinb.," vol. xx., pt. I., p. 87, &c., "On the Equilibrium of Elastic Solids," has investigated, in his third and ninth cases, problems which are closely related to those here in question in the text. Unfortunately, his calculations all assume the elasticity of the body perfect—a condition which the researches of Professor Hodgkinson have shown to be far from practically applicable to any of our known materials of construction. See also E. Clarke's "Brit. Bridge," vol. i., p. 451, as to the effects of previous strains beyond the elastic limit, on subsequent ones within the same, and transversely applied.

As respects the distribution of heat in the mass of solids, in relation to its unequal diffusion in heated guns, see Duhamel, "Sur les Equations generâles de la Propagation de la Chaleur dans les Corps" (Jour. de l'Ecole Politech., t. xiii., p. 357); and Poisson, "Memoire sur la Distribution de la Chaleur dans les Corps Solides," Idem, t. xii., p. 144, and second Mem., p. 249.

NOTE L.—(SECT. 133.) See Note C.

NOTE M.—(SECT. 141.)

SEE Note O. The Reports of M. F. le Play, Eng. des Mines (in "Ann. des Mines," 4me ser., t. iii. p. 503, and t. ix. p. 113) comprise one of the most complete accounts of the steel manufacture in England, and abroad, that has been produced. See also list of German authors at conclusion.

Steel made by the direct or puddling process, has long been a branch of industry in many parts of Germany, where it is applied with great economy, to a number of objects, for which we content ourselves with cast-iron or other material. It is afforded at prices from one-half to one-third that of our English cast-steel.

At the Exhibition of 1851, amongst the products of the Zollverein, was puddled steel from the works of Messrs. Lehrkind and Co., of Haspe, near Hagen, of very good quality, at £22 per ton, at the Works. For fine-cutting tools, or other purposes demanding a keen and persistent edge, however, it is immeasurably inferior to English cast-steel, produced by cementation.

NOTE N.—(SECT. 149.) See Note S.

Note O.—(Sect. 181.)

It appears that cast-iron field-guns have been in use in the Swedish and Danish services since 1831, the first trials dating back to 1804; and that now, after several years' experience, they are preferred to bronze guns by the Artillery of both countries. See Jacobi, "Sur l'Etat actuel de l'Artillerie Swedoise," 1849. Cast-iron field-guns have been tried in Sweden as far back as 1805; and in 1848 their horse artillery was armed with such guns. Some Swedish and Danish cast-iron field-guns were placed in the Exhibition of 1851, amongst which were—A Swedish 6-pounder, 5 ft. 5·75 ins. long; 3·828 ins. caliber; charge, 2 lbs. 7 oz.; weight of gun, 803 lbs. The British bronze gun of same class weighs 672 lbs. A Danish 6-pounder, 5 ft. 3·5 ins. long; weight, 874 lbs.

In the United States, cast-iron 6-pounder field-guns have been employed at least since 1844. They are from the established models of bronze guns of equal caliber, but increased in thickness at the breech part, without corresponding increase of weight, by a certain reduction of thickness towards the muzzle. The successful use of these *cast-iron field-guns* would appear to dispose of many of the objections that have been groundlessly urged (even by some of the local artillery authorities in the United States), and by others, against the advantageous application of *wrought-iron* to the same purpose; for very many of the objections, for example that of corrosion, apply equally to both, or with greater force to the former.

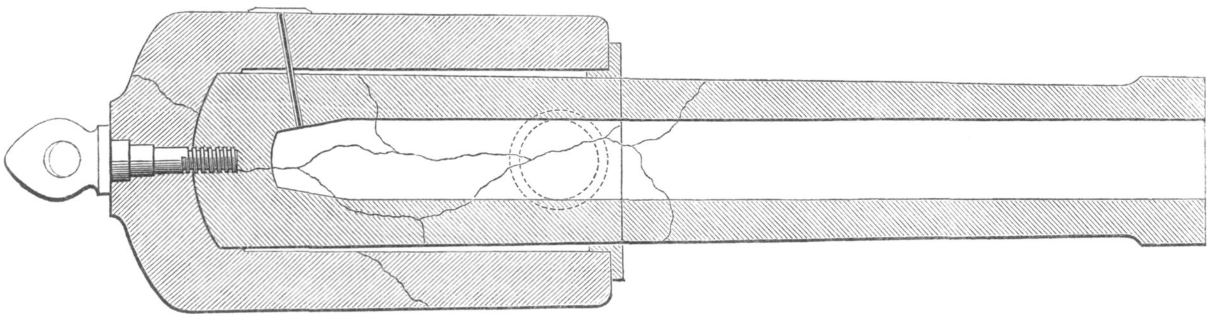
Note P.—(Sect. 190.)

A very remarkable instance of the internal tensional strains produced in cast-steel, in the process of hardening or tempering, has, since the text was written, met my eye in the pages of the "Franklin Journal," vol. viii., p. 133, in which a tolerably large cylindrical pivot for a shaft, with *a hole through it* too, in the axis of the cylinder, burst or split into two or more pieces, some time after having been hardened, with a noise nearly equal to that of a pistol-shot, and throwing the fragments several feet. The external edges of the fractures presented an arrangement of minute crystals penetrating its substance perpendicular to its external contour (like those of chilled cast-iron); thus proving that in steel, also,—although, from the minuteness of the crystals, much less marked, and generally scarce distinguishable,—the aggregation of its particles follows the general law announced in the text.

The steel guns, made and tried, by the Hanoverian and other German Governments, were all of small caliber, and their proportions much about the same as those of bronze guns; indeed, a 12-pounder, repeatedly proved at Woolwich, a year or two since, with

enormous charges, and without injury save the loss of a trunnion struck off in recoil, appeared to have a good deal a greater thickness than usual in bronze guns: it was very short. On the principles announced in the text then, these guns, possessed of an enormous surplus strength, are safe enough; but upon guns so proportioned no argument whatever can rest as to the generally advantageous character of steel guns.

A very different result awaited a much larger gun, of cast-steel, made and proved last year at Woolwich. The magnificent forging for it—which, from observation, I can state to have been of steel of extremely fine quality—was supplied by Mr. Krupp, of Essen. It was about $10\frac{1}{2}$ feet long, and as much as 17 inches diameter at the larger end. The boring and turning were effected, and the construction of the gun,—of which a longitudinal section is given below,—was under the direction of some of the authorities at Woolwich.



The steel forging—originally intended, it would appear, for a 32-pounder—was bored out to an 8-inch gun, and, when completed, the diameter round the powder chamber was about 16 inches, leaving the thickness here not more than 4 inches or $4\frac{1}{4}$ inches, or about half a caliber.

The finished steel gun only weighed about $2\frac{1}{2}$ tons; and, to carry out the established system of absorbing recoil by mere crude weight, a cast-iron jacket, or "chemise," was made to slip over it, of no less than 7 tons weight. This was bored at the bottom to fit the steel gun, which was here secured to the chemise, by the wrought-iron breech-ring screw, passing through the chemise, and being tapped into the steel. The steel gun, except here, had a free space of about an inch all round between it and the chemise; but, at the mouth of the latter, the gun was supported and kept central by a wrought-iron circular ring flange, bolted to the mouth end or face of the chemise.

The gun itself, therefore, derived no support, or reinforce, whatever, from this unwieldy mass of cast-iron round it, and on to which the trunnions were cast.

The vent was bored out right through both chemise and gun, to about $1\frac{1}{8}$ inches diameter, and a steel or wrought-iron vent was tapped through both, and rigidly connected them at this point at least.

A more injudicious and unscientific construction it would be difficult to imagine, or one that more thoroughly exposes the barbarism of the established notion as to absorbing recoil,—*seven tons of useless material, to be for ever after carried about to absorb the recoil* of a machine, the total weight of which was $9\frac{1}{2}$ tons, while that of the only part of it of any real use was $2\frac{1}{2}$ tons; and this exclusive of any gun-carriage whatever.

The gun was intended to have been proved with single, and then double, spherical shot. Several elongated shot, of various forms, had been provided for trial with it; and it appears that, confident in the presumed enormous strength of the material, the first shot fired was with a charge of 25 lbs. of powder, and one elongated shot of 260 lbs. weight. The form of the shot was cylindro-conoidal, with a recess of about $\frac{1}{2}$-inch deep, taken out for 2 inches wide, or so, round the cylindrical part at the rere of the shot, and replaced by a wrought-iron ring of the same size, and with the rere edges bevilled away towards the inside, under the idea that it should act like a piston-cup, and close all windage at the moment of explosion.

The gun burst at the first discharge, as it should have been foreseen it must do, breaking into angular, glassy, irregular fragments, like those shown in lighter lines, and shattering the chemise also into two or three huge pieces. The muzzle portion of the gun (all nearly that was outside the chemise) remained entire, and was thrown forward in the usual way. The shot was not found for some time, and then beyond the butt, over which it had flown. On examination, it was found (with some surprise) that the wrought-iron ring upon it, had been ripped off, and had either been driven forward, or had so crushed the substance of the cast-iron shot, immediately in advance of its forward edge, that the metal was here torn away and gone, leaving a sort of inclined plane, reaching some half way along the sides of the shot towards its point.

The parties interested in Mr. Krupp's manufacture are of opinion that this shot, from its malformation, stuck or became wedged in the gun, and that the latter burst from this cause, and this only. In this opinion I cannot coincide. The inertia of an elongated shot, of such an enormous weight, in proportion to its diameter (eight inches), was so great, that no doubt the wrought-iron ring may have been driven forward upon it, crushing and disintegrating the sides of the cast-iron shot before the latter began to move at all; but this would not cause it to jam in the gun; on the contrary, the moment the shot itself began to move, it would pass through, as it were, and free itself from all this *debris*, which would be swept along with it out of the muzzle. But the mischief was already done, the gun was already ruptured, before the shot had probably moved at all; this is the great and irremediable evil of elongated shot.

But, would the gun have stood an equal charge of powder and of iron, with equal windage, even of spherical shot? I believe not. If, from the formula, $\frac{1}{2}\frac{P}{g}V^2$, we calculate the maximum pressure per square inch on the gun, assuming its caliber 8 inches, or,

say, 50·5 inches area, and the length of traject of the shot to have been 8 feet, we shall find that the maximum pressure per square inch upon the gun could not have been much less than sixfold the ultimate coefficient of rupture for cast-steel; yet even this enormous strain a bronze gun might possibly have withstood for a moment with no more damage than enlargement of bore; but expose the rigid steel gun to a strain, but for an instant, greater than its ultimate cohesion for continuous force, and fracture results.

This example, then, though not conclusive, from the want of prevision that appears to have attended it, fully indicates the faithless nature of this rigid material, where its resisting powers and the forces acting upon it, are at all nearly balanced.

The immense excess of bursting force exercised upon this gun, over and above that merely necessary just to rupture it, is evidenced by the irregular and curved lines of the fractured fragments, which are only found to follow the directions indicated (in Chap. 2, text), in sound guns, exposed to bursting strains not greatly in excess of their resistances. This is very satisfactorily shown by comparing the numerous diagrams of fractured guns in the experiments made at Gavre, in 1836 (Correard, Paris, 1837, 8vo), and those of the "United States Reports" (Trübner, London, 1856, 4to), on Columbiads and other heavy guns.

The occasional apparent departure of the lines of fracture, from the lines of re-entering angles on the external contour, or other directions indicated in the text, is not, therefore, any disproof of the correctness of the views there advanced, but a consequence of *great excess in the bursting power*, which always produces angular, knife-edged fragments and fractures, in irregular curved lines, crossing each other, from causes not difficult to analyze. The fracture of steel is, however, always more of this character than that of cast or wrought iron.

I am informed a 12-pounder steel gun, at Vincennes, has been fired more than 2000 rounds, without showing any symptoms of injury, except enlargement of vent—since bouched with copper; and that it is intended to proceed with firing it up to 10,000 rounds, if practicable.

If *with a large excess of strength*, there can be no apprehension that it will not stand this test.

Note Q.—(Sects. 206 and 214.)

On the 12th July, 1855, a wrought-iron 8-inch gun was proved at Woolwich, and burst into several pieces at the first discharge.

This gun was forged at the Gospel Oak Works, Shropshire, and was proportioned in length and scantling very nearly by the established cast-iron models, for the same caliber and class of gun.

The breech-ring was forged on solid to the gun, but the trunnions had been forged separately and screwed into the body of the gun, into holes prepared with a slight reinforce of metal round each, the screw-threads being of sharp or angular form, and nearly an inch pitch. The gun was stated to have been formed by laying together longitudinally some ten or twelve voussoir-shaped heavy bars, previously forged out to form, and welding these together by continuous longitudinal weldings, the breech being also welded in; the whole was then bored out and turned.

To the eye, both externally and internally, it presented an appearance of entire soundness and perfection of material, and the result of its trial very much surprised the majority of those who were present.

The proof-charge fired consisted of 28 lbs. of powder, and two spherical 8-inch shot. The gun was split nearly in half longitudinally, with other secondary longitudinal fractures, and by diagonally transverse ones, turning out through one, and near to the other, of the places of the screwed-in trunnions. Upon examination, after the rupture, I found the wrought-iron of a quality so fine, as to answer to what is called technically "over-worked." Its fracture was everywhere confusedly crystalline, the average sizes of the facets not being, however, very large, though in some places reaching the surface of a silver penny, say, $\frac{3}{8}$-inch across; fragments were capable of being broken off, from bevilled edges of the ruptured masses, by blows, almost with the facility of cast-iron, and with the same short, crystalline fracture, although bending a little more before finally giving way.

Along the face of the principal longitudinal fracture, and commencing at 1 foot 4 inches from the bottom of the chase, or very nearly opposite the seat of the shot, was the smooth, bright, uneven ("*slickenside*" sort of) surface, that is, the evidence, in heavy forging, of a false weld. This extended for nearly 4 feet in length, or almost up to one trunnion; it reached all along, and opened right into the chase, and extended in depth into the substance of the gun about 3 inches, leaving some 5 inches or thereabouts sound (in some places less); practically, therefore, the caliber of the gun, as respects the moment of strain, was enlarged, at all the points of maximum distress, to at least 11 inches diameter, and the effective thickness of metal was reduced to less than 5 inches.

One of the most remarkable features presented, however, was the trace discoverable of the place of nearly every longitudinal weld, by a marked alteration of character in the fracture and colour of the iron at those places. The metal along these lines, which several of the fractures followed, and most markedly along the edges of the false weld, was of a silvery white colour, and arranged in large, brilliant, smooth, flat, crystalline plates, some as large in surface as a half-crown piece, say $1\frac{1}{4}$ to $1\frac{1}{2}$ inches across, through whose planes of cleavage (all lying parallel, or nearly so, to the plane of the welding between two original voussoir bars), the fractures had taken place in most instances.

The crystals had followed in their arrangement the general law given in the text; and

the fractures had followed their planes of cleavage, as the "planes of weakness," or of least resistance, in the mass.

The change of colour in the metal at these places was due, I imagine, to its having united with a certain amount of silicium, introduced with the sand in the welding process, or perhaps by cementation only, in the prolonged heating. The gun was stated to have been more or less *heated in the forging for about six weeks.* That the fracture in this instance was originated in the false weld, does not admit of doubt. It is by no means certain, however, that, had this unsoundness not existed, this gun would have borne the same proof as an ordinary cast-iron gun of the same dimensions and of the best quality; indeed, I will venture to state my conviction that it would not. This would not have been so, had a more suitable sort of wrought-iron been applied to the making its constituent bars in the first instance; the "over-worked" iron used, having been, no doubt, the result of over-anxiety, on the part of the highly respectable manufacturers of the gun, to insure its perfection, by using for it the most highly refined iron.

The long false weld was perfectly undiscernible to the eye prior to proof, though, had water pressure been applied as a preliminary test, it would probably have opened and shown.

The method of putting together the gun in longitudinal voussoirs prior to faggoting was a capital mistake, though offering some specious advantages, in the operations of welding, and possible to be carried out upon a smaller scale.

The facts are worthy of notice, as indicating the absolute uncertainty that ever must exist as to the trustworthiness of wrought-iron guns, forged in one great mass, although executed without regard to cost, and by parties anxious faithfully to produce a result of the highest excellence. Some of the evils incident to this gun might have been avoided by greater experience and judgment; but the main evil is inherent, and inseparable from every huge forging, and most so where the weldings are most numerous.

The following document, addressed to the American Government, is so instructive upon all that relates to this subject, that I print it at length:—

"*Report on the Explosion of the Gun on board the United States Steam-Frigate, 'Princeton.'*

"The Committee on Science and the Arts, constituted by the Franklin Institute of the State of Pennsylvania, for the promotion of the Mechanic Arts, to whom was referred, by the Legislature, for investigation, the cause of the explosion of the gun on board the steam-frigate, 'Princeton,' report:—

"That they commenced their labours on the 5th of April last (1843), at a preliminary meeting, on board the 'Princeton,' for the purpose of inspecting the gun in place, and for arranging the order, &c., of the investigation. The deliberations of the Committee at this

meeting led them to the conclusion, that a complete and satisfactory examination of the causes of the explosion would render it necessary to institute a judicial procedure in reference to the method of proving and firing the gun, requiring a power not possessed by a Committee of the Franklin Institute. This difficulty being presented to the applicants, the Committee were subsequently requested to 'investigate the material and workmanship of the gun,' and they have consequently limited their inquiry to this part of their original instructions.

"In the first place, the Actuary of the Institute was directed to address a series of questions, furnished by the Committee, to Messrs. Ward and Co., the manufacturers of the gun; and one of the Committee was requested to make such drawings and measurements as would facilitate the investigation; to another member of the Committee was intrusted the duty of causing to be cut from the gun a number of pieces of iron, in the form of bars, by means of a planing machine or other instrument, so as not to change the texture of the metal, and which might serve as specimens for testing the quality of the material. The largest of these bars was afterwards given in charge to a member of the Committee, visiting Boston, to be tested by an apparatus for breaking iron in that city; and the other bars were placed in the hands of the other members of the Committee, to be experimented on, in Philadelphia, by the breaking apparatus belonging to the Franklin Institute.

"These duties, assigned to the several members, have been faithfully executed, so far as time and opportunity would permit.

"I.—*Inspection of the Gun.**—The Committee found the gun broken across, within the trunnion bands; the front part remaining entire, and still, at the time of inspection, in its original connexion with the carriage. The breech part had evidently split into three large, unequal, and irregular pieces; two of these, according to testimony, passed overboard, and have not since been found; the other piece fell on the deck, at the distance of about 30 feet from the carriage. The appearance of the cross fracture at the trunnion bands is shown in Fig. 3, and in this the relative size of the faces of the fractures, left by the three segments blown off, exhibited. The only remaining fragment of the breech part of the gun, that which fell on the deck, is shown in Fig. 1. It is 5 feet long, and at the larger end embraces little more

* The precise dimensions of the "Princeton's" gun are not given. It was replaced by a wrought-iron gun, forged by Messrs. Horsfall, of Liverpool (Mersey Steel Company), which had the following dimensions, and which are probably much the same as those of the original gun:—

Caliber, ...	12 inches.
Length of chase, ...	11 feet.
Thickness at place of charge, ...	7¾ inches.
Weight of shot, ...	219 lbs.

This gun was proved at Liverpool, with 44 lbs. of powder, and two shot of the above weight, and remained uninjured.

than half of the entire circumference of the gun (see Fig. 2) at the middle of the fragment. The transverse section forms a sector of a circle of about 120°; and at the end next the trunnions, where it is separated from the forepart of the gun, it forms a sector of about 90°, as is shown at *a*, Fig. 3. It is evident to the Committee, as before stated, that the breech part split into three large fragments; but it would appear, from the testimony of persons on board at the time of the explosion, that, besides these, a number of small pieces were thrown off in different directions, some of which are said to have passed through the sails: of the number and size of these pieces, the Committee have no means of judging.

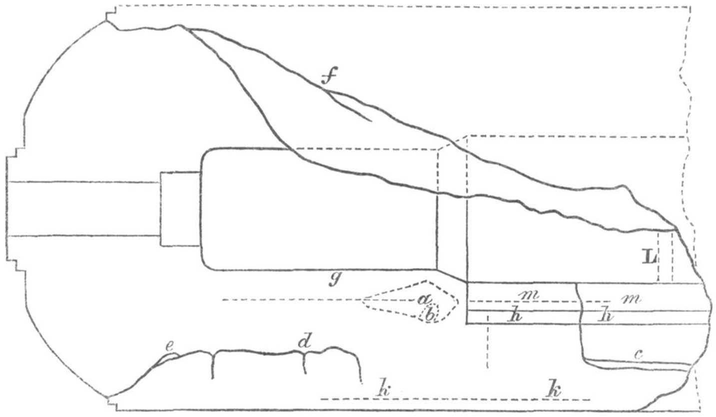


Fig. 1.

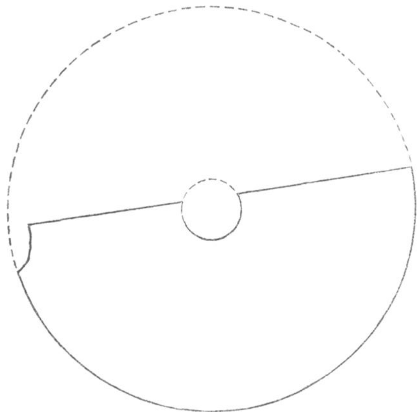


Fig. 2.

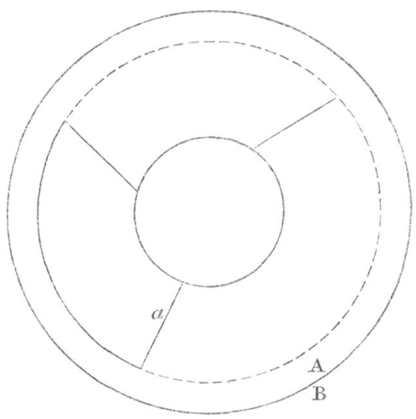


Fig. 3.

FIG. 1.—View of the fractured surface, and of the interior of the bore of the large fragments.

FIG. 2.—Section of the fragment across the large end next the breech.

FIG. 3.—Section across the small end of the fragment, shown in Fig. 1, near the trunnions. A—Outline of gun under the trunnion-bands. B—Outline of gun at the breech.

SCALE.—Three-fourths of an inch to the foot.

"II.—*Mode of Construction, and History of the Material of the Gun.*—In reference to the mode of constructing the gun, and the history of the material of which it was formed, Messrs. Ward and Co. readily furnished direct answers to all the questions proposed to them, and expressed a laudable desire to give the Committee any information in their possession which might tend to throw light on the investigation.

"The following are the questions proposed to Messrs. Ward and Co.:—

"'1. Of what description, and from that locality, was the ore from which the iron was made?

"'2. By whom, and where, was the iron made? Was the cold or the hot blast used? Was, or was not, the iron puddled? Was it manufactured by hammering, or by rolling, or by both processes?

"'3. In what state, and of what size, were the pieces of iron of which the gun was composed? Was the iron introduced into the work in the state of blooms or bars? If in bars, of what dimensions were they? And were the faggots trimmed?

"'4. Was any substance used to assist in welding? What was the aggregate time during which the gun was kept heated? And what was the average interval during which the surface was exposed, in a heated state, between the weldings?

"'5. Describe the mode of manufacture of the gun, and the position of the bars severally, as they were welded together.

"'6. What was the diameter of the shaft made by the first faggot, and the whole diameter of the shaft made by longitudinal bars?

"'7. Forward, if possible, specimens of the iron of the gun.

"'And, in conclusion, the Committee will feel much indebted to you for any information which may appear to you to be of interest, in reference to the investigation, and especially in reference to the change of structure which is supposed to take place in iron under long heating.'

"To these questions the following answers were given, in the order in which they were proposed:—

"'1. The ore, from which the bars used in the gun were chiefly made, was from beds in the vicinity of Clintonville, in this State (New York), and known as the Arnold and Palmer Ore, and we suppose it was used in about equal proportions.

"'2. The principal part of the iron was made at forges on the Ansable River, in Clinton County, by two or three different individuals, and we believe that the hot blast is used by them all. A few hundred-weight of the iron, used on the small end of the gun, in lengthening it out, was puddled by ourselves, on the old plan, with bituminous coal, and without artificial blast, and the whole throughout was manufactured by hammering alone.

"'3. Much the largest part of the iron used was in the form of bars, four inches square, and in length of about $8\frac{1}{2}$ feet. No blooms were used. A part of the bars, we should

think about one-half, were trimmed at the end, the others not; though the bars in the faggot, with which we commenced, reached to the extreme end of the breech, and was then drawn down from twenty inches diameter to about half that size, and then cut off; by which means the fag ends were effectually got rid of, and, at the same time, the fibre of the iron drawn round the end of the breech, to give it strength.

"'4. No substance whatever was used to assist in welding. *Forty-five and a quarter 'turns,' or days' work*, were expended on the gun, from the time of commencement to its completion; *during which time it was, of course, kept more or less heated;* and the average time in getting a welding heat, when at the full size, was, on the breech, about four hours, and, on the small end, two and a half to three hours.

"'5 and 6. The work was commenced with thirty bars, of dimensions the same as before described, laid up in the usual manner of a faggot. These were heated and welded together, and, when so done, rounded up, forming a shaft from twenty to twenty-one inches in diameter. Iron was then laid on to enlarge the size, being for the most part prepared in the form of segments, partly from scraps of our own working, and partly from bars, and made of different thicknesses, to suit the position for which they were intended on the gun. The weight of them must have varied from about 200 to 800 lbs., the heaviest ones being put on the breech, on which were laid two tiers, or strata, the one being first welded, and then the other upon the top of it. They were of such length usually, that three of the segments reached round the body of the gun.

"'7. We have but two small pieces of the gun, which we had chiselled off from one of the fragments, and which we wish to preserve. We would send them, however, were it not easy for you to get supplied in the same way.

"'In conclusion, we beg to remark, the iron was such as we had on hand when the gun was ordered, and was not made with any special reference to it. It was what we agreed to use in it, and was recommended by us as iron of a good and suitable quality; and of this fact we have evidence the most ample. We had no time for preparation of any sort; the order for the gun being given on or about the 4th of July, and the work commenced in two or three days afterwards. The iron appears, to some extent, crystallized, though we have seen instances of good iron, broken by a sudden and violent blow, appearing much more so. With regard to its density, no doubt this will vary slightly in different parts of the gun; some parts having been expanded, by long heating, after it had become of such a size that no hammers, at present known, could affect it much,—though the hammer under which this piece was made weighs 15,000 lbs. The weight of the gun, before being bored, was 27,390 lbs. Iron, when long heated, and not much drawn, we apprehend, in all cases loses something of its fibrous properties, and assumes a more crystalline appearance.

"Your Committee, we trust, are aware that the gun stood a charge of $49\frac{6}{10}$ lbs of

powder, with a ball, in the coldest weather of the past winter, and this under the disadvantage of being secured firmly down, and not in a carriage where it could recoil. It occurs to us to mention, that the bands which we made for the other gun, and which held it together for more than a year past, were made from the same kind of iron as that of the exploded gun.'

"Although the information contained in the answers of Messrs. Ward and Co. rests on voluntary testimony, yet the Committee place the fullest confidence in its accuracy, so far as it is derived from the personal observation of these gentlemen. The answers, however, do not state distinctly the process of manufacturing the iron of which the principal part of the gun was made; and, on this point, the Committee have since received information, also entitled to credit, that, at the forges mentioned by Messrs. Ward and Co., the iron is formed directly from the ore, and without piling. Although iron, thus prepared, is called, by some, a good 'merchantable article,' the Committee consider it of an inferior quality for purposes where great strength is required.

"III.—*Examinations relative to the Homogeneity of the Metal, the Welding, &c.*—In order to a preliminary examination of the quality of the material, pieces from different parts of the large fragment were broken off, and the fresh fracture exhibited by these carefully inspected. The surfaces of these pieces were found to vary from a fine granular to a coarse crystalline texture; and, in one specimen, the face of a crystal was exhibited, three-fourths of an inch long, and half an inch wide. The faces of the crystals were not in the general plane of the fracture, but in various planes; and the comparison of all the pieces fully showed great want of homogeneity in different parts of the gun.

"It may, however, be proper to remark in this place, that the Committee were convinced, from their own experiments during the course of this investigation, that the difference of the appearance of the fracture of different pieces of iron depends very much on the manner in which the breaking has been produced. In two fractures made in the same bar,—the one by indenting with a chisel, and then breaking across an anvil; and the other by a gradually increasing pull,—the latter exhibited a fibrous structure, without the appearance of a single crystal; while the other was pronounced, by a workman, to be the fracture of a piece of inferior crystalline iron. It also appears, from the experiments of the Committee, that although the fibrous fracture indicates a considerable degree of ductility, it can, by no means, be relied on as an indication of the tenacity of the metal. In one case, two pieces of remarkably soft and pliable iron, which exhibited a perfectly fibrous texture when pulled apart, were found to possess about four-fifths of the tenacity (i. e. ultimate cohesion) of a piece of iron which exhibited, under the same circumstances, a granular texture.

"The Committee, however, are convinced, that when the fractures are produced in the same manner as by means of a sudden transverse force, the appearance of the surfaces

does afford, to an experienced eye, an indication of the quality of the iron, and that the same appearance offers a ready method of determining the homogeneity of the structure of a large mass.

"The next object of examination to be described was the surface of the original fracture of the large fragment of the breech. This exhibited, in several places, traces of the original bars of which the gun was constructed; also spots indicating a want of perfect continuity in the metal,—which was the more evident, as these were, in some cases, covered with a brittle scale of the oxide of iron, of the thickness of a sheet of drawing-paper. The position and relative size of one of these spots is shown at *a*, in Fig. 1. It is between 9 and 10 inches long, and, in the broadest part, 3 inches wide; it approaches, at its nearest part, to within three-fourths of an inch of the chamber, and may have extended into it in another plane oblique to that of the general fracture. Within this spot was observed what, at first, appeared to be an imbedded lump of stone; it was probably, however, a mere scale of slag, since it was lost sight of in the subsequent operation of cutting the iron. The Committee think it probable that, from the direction in which the pieces must have been blown from the gun, and other circumstances, the rupture commenced near this spot, and that it was the approximate cause of the rupture taking place in the plane exhibited, rather than in any other.

"Besides the spots indicating a want of continuity in the metal in the plane of the fracture, the edges of many others, in different planes, were observed; also a wide solution of continuity was shown throughout a cylindrical surface, concentric with the bore, and extending, in one place at least, entirely around the fragment. This was evident from the fact, that oil, poured in at the upper side, came out at *a*, after passing through a distance, within the fragment, of about 3 feet. Another opening, in the prolongation of the cylindrical surface, is shown at *c*. The sides of this were separated to a distance of a quarter of an inch, and, by inspecting these, it was evident that they had never been welded: into this opening a wire was thrust, to the depth of 10 inches. From the end of the same opening, a crack extends into the bore of the gun, as is shown in the drawing. At *e* is shown the section of a small cavity of a triangular form, the longer side of which was about an inch, and the shorter half of that length, which has the appearance of having never been filled up. The large solutions of continuity concentric with the bore were, in all probability, at the place where the large masses—described in the answers of Messrs. Ward and Co.—commenced to be welded on to the longitudinal shaft.

"IV.—*Experiments relative to the Quality of the Material of the Gun.*—In reference to the experiments instituted for the purpose of testing the strength of the iron, it is important, in the first place, to refer to the fact, that the pieces of iron were all cut from the large fragment of the breech, and, therefore, from the immediate part of the gun where the fracture occurred. The bar sent to Boston, to be experimented on by a member of the

Committee in that city, was cut from the wall of the chamber, lengthwise of the fibre: its position is shown at *g*, in Fig. 1. For the purpose of comparison, the same member of the Committee was furnished, by Messrs. Ward and Co., with two bars of iron taken from the same parcel, and supposed to be of the same quality as that used in the construction of the gun.

"The following is a Report of the experiments and observations made with these bars in Boston, so far as they have an immediate bearing on the questions to which the Committee are restricted. It should be recollected, that they were made by one of the members of the Committee, and without a knowledge of the results obtained in Philadelphia by the other members.

"'The bar cut from the body of the gun was reduced, in a planing-machine, to the size of 2 inches square, and was subjected to a transverse strain, supported at both sides on knife-edges 20 inches apart, and the weight applied in the middle. The different weights applied, with the deflections, and the permanent set caused thereby, were as follows:—

Weight applied.	Deflections.	Permanent Set.
lbs.	Inches.	Inches.
10,800	·35	·30
12,825	·61	·55
13,950	·94	·87
15,570	1·22	1·15
16,650	1·52	1·44
17,300	1·83	1·75

"'The bar endured this strain without exhibiting any cracks, or other indications of approaching rupture. One of the original bars, having the same dimensions, was tried in like manner, and gave similar results.

"'By these trials it appears, that so far as respects the quality of stiffness, the iron has undergone no change in the process of forging the gun.

"'To determine the tensile strength of the iron, or its power to resist being torn asunder by a force applied in the direction of the length of a bar, three specimens, taken from each bar, were reduced to a suitable form for breaking by tension, in a turning-lathe, in order to have the material in the same state as it existed in the bars, undisturbed by any heating or hammering. The third specimen from each bar was drawn down under a welding heat, at a common smith's forge. All of them were reduced, in the part where the fracture would occur, to a uniform diameter of six-tenths of an inch.

"'The following results were obtained:—

"'I.—From the original bars, representing the quality of the iron before welding the gun:—

	lbs. per Square Inch.	
First specimen, from bar A, broke with	45,359	
Second ,, ,, ,, ...	45,359	
Mean, ...		45,359
First specimen, from bar B, broke with	50,930	
Second ,, ,, ,, ...	46,155	
Mean, ...		48,542

"'II.—From the same bar, drawn down under a welding heat:—

	lbs. per Square Inch.	
One specimen, from bar A, broke with	39,375	
,, ,, B, ,, ...	49,338	
Mean, ...		46,356
Mean of six specimens from original bars, . . .		46,086

"'III.—From the bar cut from the body of the gun:—

First specimen from this bar, unaltered by heating or hammering, broke with	40,585	
Second specimen from this bar, unaltered by heating or hammering, broke with	36,606	
Mean, ...		38,595
One specimen from this same bar, drawn down under a welding heat, ...		52,521

"'In order to compare the iron used in the construction of the "Princeton's" gun with other kinds of wrought iron, the following additional specimens were tested:—

	lbs. per Square Inch.
Russia iron, the common flat bar, one specimen, ...	62,644

English rolled iron, from different bars—

	lbs. per Square Inch.	
Banke's, first specimen, ...	56,896	
,, second ,, ...	56,169	
Mean, ...		56,532
Low Moor, first specimen, ...	58,888	
,, second ,, ...	53,317	
Mean, ...		56,103

		lbs. per Square Inch.	
American hammered iron, from different bars,—			
Bridgewater, Mass., first specimen,	. . . . .	58,488	
" " second "	. . . . .	49,338	
Mean,	. . . .		53,913

"'Recapitulation of all the kinds of wrought-iron tried, showing the actual and the proportional cohesive power of each at one view:—

		lbs. per Square Inch.	Proportional Strength.
Russia iron,		62,644	1·0000
English iron,	Banke's,	56,532	·9024
	Low Moor,	56,103	·8955
American,		53,913	·8605
Iron of the "Princeton's" gun.	Original bars,	46,086	·7356
	As in the gun,	38,595	·6161
	Same, re-worked,	52,521	·8383

"'The results of this examination appear to show, that the iron used in forging the "Princeton's" gun was originally of an inferior quality, having only about three-fourths the strength of English iron. It appears, also, that *the original strength of the iron is considerably impaired by the process of welding it into so large a mass as that which formed the gun,—the strength, before and after welding, being about as* 6 *to* 5.'

"In the opinion of the General Committee, the specimen of English iron, used in this comparison, is of a good quality, while that of the American is not of the best kind.

"The following are the results of experiments made at the Hall of the Franklin Institute, in reference to the quality of the material of the gun:—

"I.—Experiments with the metal, in the state in which it existed in the gun:—

	lbs.
First specimen, cut from position marked *h*, near the bore of the gun, being part of the shaft made of the longitudinal bars; strain, lengthwise of fibre, broke with a tension on the square inch of	38,400
Second specimen, from the same place, circumstances same, broke with less than	25,800
Another specimen, from position marked *h*, near the outside of the gun, across the fibre, ...	31,100
Second specimen, from same place, circumstances same, less than . . .	31,100
Third specimen, continuation of the preceding, towards the breech, . .	41,400
Specimen in tangent to circle of bore across fibre of shaft, made by the longitudinal bars, from position marked *L*, broke with, ...	23,700

"II.—Metal from the gun, annealed, but not hammered:—

	lbs.
First specimen, from position marked *h*, lengthwise of fibre of shaft, made of longitudinal bars, broke in two places, the first breaking-weight being,	36,300
And the second breaking-weight, ...	39,100
Second specimen, from same place, ...	32,800

"III.—Metal from the gun, drawn down, at a welding heat, under forging-hammer:—

First specimen, from the position marked *m*, ...	58,000
Second specimen, from the same, ...	68,950

"Recapitulation:—

1. The average tensile force with which the specimens from the interior of the gun broke, when strained in the direction of the fibre, is less than	32,100
2. The specimen from the interior, strained in a direction across the fibre, gave	23,700
3. The specimens from the outside of the gun, across the fibre, gave an average of less than	45,333
4. Annealed specimens from the interior, strained lengthwise of the fibre, gave an average of, ...	36,067
5. The average of all the specimens from the gun, not hammered, is . .	33,300
6. The average of the specimens worked down under the hammer is, . .	63,475

"The general conclusions from these results are the same as those from the experiments made by the member of the Committee in Boston, so far as the two series can be compared.

	lbs.
1. The average strength of the iron, as it existed in the gun, from both series, is	33,586
2. The average strength of the iron from the gun, after being drawn down with the hammer, from both series, is	59,824
3. The average strength of the original bars, from the experiments of the first series, is	46,950
4. The average strength of good American iron, from the investigation of a former Committee of the Institute, is	60,000

"No experiments were made, at the Hall of the Institute, on the original bars of which the gun was formed, owing to a misapprehension, by Messrs. Ward and Co., of the request of the Committee (see Question 7, and its answer); none of the metal, in its original state, was sent to Philadelphia. The conclusion, therefore, in reference to the quality of the original bars, rests on the experiments made in Boston. In the accuracy of these experi-

ments, the whole Committee have the fullest confidence; and, in this point, the result is also corroborated by the fact of the large size of the bars, and that there is no evidence that the iron had been piled.

"Besides the experiments given in this Report, the Committee commenced a series of others, on the effect produced in a mass of iron by long heating, without cooling—by heating and cooling alternately—by subjecting the metal, for several weeks, to a constant vibration, &c.; but the Committee are not clearly of opinion that they can depart so far, from the inquiry to which they were limited.

"V.—*Conclusion.*—From the results of the whole investigation, the following facts are derived:—

1. The iron of which the gun was principally made was capable of being rendered of a good quality by sufficient working.
2. In the state in which the iron was put into the gun, it was not in a sufficiently good condition for the purpose to which it was applied.
3. As the metal existed in the gun, it was decidedly bad.
4. As to the manufacture of the gun, the welding was imperfect.

"These facts relate exclusively to the gun submitted to the examination of the Committee, and are derived from immediate experiment and observation; but, besides giving these to the public, the Committee feel bound to express the opinion, that, in the present state of the arts, the use of wrought-iron guns of large caliber, made on the same plan as the gun now under examination, ought to be abandoned, for the following reasons:—

1. The practical difficulty, if not impossibility, of welding such a large mass of iron, so as to insure a perfect soundness and uniformity throughout.
2. The uncertainty that will always prevail in regard to imperfections in the welding; and—
3. From the fact that iron decreases very much in strength from the long exposure to the intense heat necessary in making a gun of this size, without a possibility, with the hammers at present in use in this country, of restoring the fibre by hammering. At the same time, the Committee would not wish to be understood as expressing any opinion whether the construction of a safe wrought-iron gun, upon some other plan, is practicable or impracticable, in the present state of the arts, inasmuch as this subject has not been referred to them by the Department.

"By order of the Committee,

"WILLIAM HAMILTON, *Actuary.*

"*Philadelphia, August* 8, 1844."

Nothing can more strikingly show the deteriorating effect of forging into large masses (however done) upon the tenacity of wrought-iron, than the facts of the preceding Report, nor the uncertainty of the process, as respects welding. That the latter difficulty may be greatly mitigated (though it cannot be removed), by pre-eminent skill on the part of the hammer-man, is proved by the success of the Mersey Steel Company, in the duplicate perfected by them of the gun which failed for the "Princeton," and still more in the stupendous and apparently perfect forging they have now almost finished into a gun for Government,—no doubt by far the largest ever made in one piece, being 13½ feet length of chase, 13 inches caliber, 14 or 15 inches thick at the charge, and about 9 inches at the muzzle; a solid shot of which will weigh 300 lbs.

NOTE R.—(SECT. 214.)

SEE Note Q. Late experience has shown me, that in very large cylindric masses of forged wrought-iron (i. e., of 3 feet diameter, and upwards), amongst the other abnormal circumstances involved in their production, is that of their frequently rending or tearing, internally, in planes nearly parallel with and about the axis, though not always in it,—presenting characters similar to those described in Section 217; and the cause appears to be, that in the progress of cooling of such a mass, the exterior cools first, and becomes rigid, while the internal portions are still red-hot and soft. The external parts would contract as they cool; but they already grasp, in perfect contact, the still hot interior; the exterior, therefore, cannot contract fully, but becomes solid under constraint circumferentially,—partly itself extended, in virtue of its compressing the still hot and soft interior; the latter at length, also, becomes cold and rigid; but *its* contraction is now resisted by the rigid arch of the exterior, with which it is surrounded. The contraction of the interior, therefore, is limited to taking place radially outwards from the centre; and thus the mass rends itself asunder in some one or more planes parallel to the axis of the cylinder.

In a cylindric mass of forged iron, varying from 24 to 36 inches in diameter, rents of 18 inches in width across a diameter were found, with jagged *counterpart surfaces*, clearly *torn* asunder, and about ⅜ths of an inch apart at the widest or central part; and the fact is most instructive as to the enormous internal strains that must exist, from like causes, in cast-iron guns and mortars of large size.

It is probably from this cause that more or less hollowness is found in the centre of almost *every large forging*, greater in proportion as it is larger. The difficulty is one not easily overcome: very slow, and, as far as possible, uniform cooling of the whole mass in an annealing oven, suggests itself as one; but this has disadvantages, in enlarging the crystalline development of the metal; or providing a central cylindric opening, so as to cool both the circumference and the centre together.

Note S.—(Sect. 265.)

Physical Constants of the Materials for Gun-founding.

The Reports of Colonel Talcott and of Mr. Wade ("Ordnance Reports, United States Army, 1856") indicate generally that the ultimate cohesion, both of cast-iron and of bronze, rises with increase of density, although several apparent anomalies are introduced, that would have disappeared, under more rigorous and distinct methods of putting the questions to experiment. Many of the data of these Reports, nevertheless, are amongst the most valuable and important that have yet appeared.

In bronze gun-castings the extremes of density and tenacity were found to vary from the gun-head's specific gravity 8·353, and with so low an ultimate cohesion as 26011 lbs. per square inch, up to specific gravity 8·896, and cohesion 56,360 lbs. per square inch. The density was found steadily to increase with increased head of fluid metal, varying in the same gun, e.g., one of about 90 inches length (12-pounder), thus:—

Top of gun, specific gravity, . .	8·523;	cohesion, 23,108 lbs. per square inch.	
Base of gun, ,, . .	8·775;	,, 36,672	,,

In another gun the cohesion varies from 26,426 lbs. to 52,192 lbs. per square inch. At about $\frac{6}{10}$ths of the ultimate cohesion, bronze is stated to begin to stretch and permanently lose form; this estimate is probably much too high.

It is certainly surprising to find, throughout these generally valuable and elaborate Reports, the most perfect neglect of the all-important constant of *extension in relation to strain*. Ultimate cohesion, the *final* force of rupture, is systematically, and in very numerous examples, ascertained, but the amount of *extension* by less strains, prior to rupture, is not only neglected, but even the value of ascertaining such a constant at all, appears to be unknown; for the testing machine, figured and described in detail, though capable of determining the ultimate resistance to tension, compression, and transverse strain, and the resistance and angle of torsion, appears actually *incapable* of giving the amounts of extension, under various strains, with any pretension to accuracy; the longest specimen possible to be tested thus, being limited to under 1 foot long (Prof. Hodgkinson's experiments on extension of wrought-iron were conducted on bars of *fifty feet* in length), so that it would really appear that the importance of the coefficients T_e and T_r remains as yet unrecognised by the United States Artillery authorities; and the same seems to be the case at Woolwich, where the testing machine is a duplicate of the American one, and, I believe, imported thence. Compression, in relation to load or strain, this machine appears to determine, although certainly with immeasurably less accuracy, than in the methods employed by

Prof. Hodgkinson with long bars; and amongst the results of this class, I find almost the only trials of the crushing force for steel that I have met, thus:—

Cast-steel, not hardened, ...	198,944	lbs. per square inch.
„ hardened low temper, .	354,554	„
„ hardened mean temper, .	391,985	„
„ hardened highest temper,	372,598	„

It seems scarcely credible that no series of experiments appears ever to have been made by physicists or artillerists hitherto, upon the compressive force for bronze; at least I have searched for such in vain. Its importance, as one of the data for calculation, has been pointed out in the text.

Some experiments are subjoined, for which I am indebted to the kindness of Colonel E. F. Wilmot, R. A., Superintendent of Gun Factories, Woolwich Arsenal, who obligingly had them recently made, at my request.

The series No. 4, appears to be of a character to use in practice; the others, though not applicable so directly, are not devoid of practical interest.

Experiments made at the Royal Gun Factory, Woolwich Arsenal, on the Resistance of Bronze Gun Metal to Compression, April, 1856:—

Specimen.	Specific Gravity.	The pressure is in lbs., and the compression in decimals of an inch.												
		lbs. 2500.	lbs. 5000.	lbs. 7500.	lbs. 10000.	lbs. 12500.	lbs. 15000.	lbs. 17500.	lbs. 20000.	lbs. 22500.	lbs. 25000.	lbs. 27500.	lbs. 30000.	lbs. 32500.
No. 1, A	8·3194	·025	·057	·12	·17	·22	·265	·30	·34	·38	·417	·455	·493	·540
No. 1, B	8·2954	·03	·078	·15	·22	·272	·357	·47	·56	·586	·612			
No. 1, C	8·2827	·021	·061	·131	·191	·248	·280	·330	·371	·415				
Mean	8·2992	·208	·065	·134	·194	·247	·301	·370	·424	·460	·514			
No. 2, A	8·6811*	·01	·035	·100	·161	·219								
No. 2, B	8·3641	·005	·022	·078	·138	·200	·250	·315						
No. 2, C	8·3263	·01	·031	·08	·140	·210	·260							
Mean	8·4572	·008	·029	·086	·136	·209	·240	·315						
No. 3, A	7·9171	·005	·060	·130	·200	·252	·308	·359	·401	·450	·490	·530	·563	·592
No. 3, B	7·9511	·013	·072	·145	·211	·270	·322	·370	·420	·460	·500	·540	·570	·610
No. 3, C	8·1936	·01	·060	·135	·200	·259	·310	·370	·430	·489				
Mean	8·0209	·009	·064	·137	·203	·260	·313	·366	·417	·466	·495	·535	·566	·601
No. 4,† A	8·7068	·005	·025	·100	·170	·223	·270							
No. 4,† B	8·6723	·005	·029	·095	·152	·202	·250	·292	·348	·379	·420	·460	·495	·522
No. 4,† C	8·7077	·001	·058	·143	·192	·202	·288	·325	·365	·408	·450	·490	·521	·550
Mean	8·6956	·004	·037	·113	·171	·209	·269	·308	·356	·393	·433	·475	·508	·536

* This trial was repeated several times, with the same result.

† The results of this experiment, being made of metal more homogeneous, are perhaps the most correct; but it is desirable to use larger specimens.

Specimens marked Nos. 1, 2, and 3, were cut from a "runner" of a cast, of a 24-pounder howitzer, thus:—

B .... A

× ... 12″ ... × ... 4″ ... × ... 3 ft. 6 in. ... × ... 4″ ... × ... 3 ft. 6 in. ... × 4″ ... × ... 12″ ×

No. 1. No. 2. No. 3.

A is the upper and B the lower end of the cylindric "runner," which was $2\frac{1}{2}$ inches diameter. The runner, of course, stood vertically in the mould when being poured.

The centre of each piece, Nos. 1, 2, and 3, was turned into a (solid) cylinder, 1 inch in length and 0·5-inch diameter, A, B, C.

Composition of the metal used for charging the furnace in the casting of the gun:—

	Cwt.	qrs.	lbs.	
Head, ...	13	3	22	
Copper pigs, . .	25	1	4	
Hard metal, . .	0	2	8	(half copper and half tin.)

The amount of compression was noted after each 2500 lbs. pressure, as given in the Table.

The testing was discontinued when the axis of the specimen became oblique to the pressure. This occurred in all the specimens, probably from the smallness of the base, or want of homogeneity in the composition (want of the line of pressure remaining perfectly invariable?—R. M.)

The power of the testing machine is limited to the greatest pressure given in the Table.

Specimens No. 4 were cylinders taken from the cascable of a 24-pounder howitzer, and divided into—A the top, B the centre, and C the bottom, cast under the pressure, including the "dead head," of about 10 feet.

The time occupied in obtaining the results averaged two minutes for each 2500 lbs.

The American experiments embrace some excellent results as to resistance to torsion. The following, though not a summary, may serve as an example:—

Comparative Resistances to Torsion of the three Materials for Cannon.

		Ultimate weight.	Ultimate angle of Torsion.	Strain at Torsion, angle of 0° 30′.	Transverse strength, $S = \frac{lw}{46d^2}$.
Cast-Iron, Greenwood, American Iron, ...		8799	16°	6447	7036
Nos. 1 and 3, mixed, . . .		9752	10°·5	6611	9755
Nos. 1 and 2, mixed, . .	1,	10467	16°·7	7000	9212
	2,	7847	21°·7	4723	7440
Nos. 1, 2, and 3, mixed, . .		9711	14°·0	6793	8792
Wrought-Iron, . . .	1,	5546	17°·5	4289	
	2,	5399	16°·6	3779	
	3,	5450	39°·7	3197	
Bronze, ...		5511	98°·0	2021	

The transverse strength of some of these cast-irons was found to be nearly doubled in passing through only *four* remeltings in place of thirteen.

The torsion bars were about 2 inches diameter, and 15 inches between the points of twist.

The experiments recorded, which are very numerous and valuable as to the relations between ultimate tenacity and specific gravity in cast-iron, are quite in accordance with my own former experiments (sections 55, 56, 57), and with the statements of the text; several apparent anomalies, left without explanation in the United States Reports, being accounted for by the application to them of the principles advanced by myself.

The following Table presents, in one view, most of the constants for *cast-iron* suited for gun-founding, deduced by the American experimenters:—

Cast-Iron.

Class of Experiments.	Specific Gravity.	Resistance to Tension.	Resistance to Transverse Strain.	Resistance to Torsion.	Resistance to Compression.	Hardness or Resistance to Indentation.	Ratio of Torsion to Compression.
1	7·087	20877	6084	6176	99770	12·16	1 : 4·78
2	7·182	30670	7587	8341	139834	18·03	1 : 4·56
3	7·246	35633	8806	9659	158018	25·42	1 : 4·15
4	7·270	39508	9158	9827	159930	25·59	1 : 4·05
5	7·340	32458	9274	9065	167030	30·51	1 : 5·00
Means,	7·225	31829	8182	8614	144916	22·34	1 : 4·51

The experiments as to *hardness* were made by *pressing*, under a constant load, a rectangular, prismatic, sharp steel tool, into the several metals, observing the depth, length,

and breadth of the prismatic hollow produced, and considering the hardness to be in each case inversely as the volume of the material thus displaced. The results thus obtained are, no doubt, of value; but it admits of question whether, for artillery purposes, the steel prism should not be *impelled* by the impulse of a constant weight, at a constant velocity, i. e., falling from a constant height, instead of being merely slowly pressed into the metal; and it is further obvious, from the remarks of the text (chaps. 27, 28, 29, 30), that neither method will afford any true measure of the abrasion and wear of guns in service.

The following Table is a *resumé* of the properties of the four principal materials for ordnance, collected from the American experiments, and may be usefully compared with the Table XIV. of the text:—

Physical Properties of the Materials for Ordnance.

Metals.		Specific Gravity.	Tenacity.	Tranverse Strength.	Torsion.		Resistance to Compression.	Hardness.
					At 0° 30′.	At rupture.		
Cast-iron,	min.	6·900	9000	5000	3861	5605	84529	4·57
,,	max.	7·400	45970	11500	7812	10467	174120	33·51
Wrought-iron,	min.	7·404	38027	6500	3197	. . .	40000	10·45
,,	max.	7·858	74592	. . .	4289	7700	127720	12·14
Bronze,	min.	7·978	17698	. . .	2021	5511	. . .	4·57
,,	max.	8·953	56786	. . .	. .	. . .	. . .	5·94
Cast-steel,	min.	7·729	. . .	. . .	. .	. . .	198944	. . .
,,	max.	7·862	128000	23000	. .	. . .	391985	. . .

The strongest is to the weakest cast-iron thus as 5 : 1 in direct tension; as 2 : 1 in transverse strain, torsion, and compression; and as 7 : 1 in hardness. Bronze varies in tenacity as 3 : 1. The Reports state that "the properties of metals, which are the most essential in the manufacture of cannon, are *tenacity* and *hardness*, and, as holding an intimate relation to these, *density;*" but it is surprising to find that nothing is said of the importance of *extensibility within the elastic limit*, which, I would hope, the principles enunciated in the text have sufficiently shown to be, next to cohesion itself, the most important physical constants that relate to the materials for the construction of cannon; one, the past neglect of which has been productive of more failure, and abortive, but costly, attempts at improvement of ordnance, than any other.

Note T.—(Sect. 266.)

Field Batteries of Wrought-iron Guns.—A recent date has seen the reduction to one caliber (12-pounders) of the whole field-train of France, the realization of the ideas first developed by her distinguished ruler.

The advantages appear now confessed by all, and may be summed in great degree in two sentences—simplification and increase of power. The latter has resulted much from the abandonment of all the guns of smaller caliber.

It does not appear to admit of dispute that increase of caliber, and therefore of range, must be always advantageous to the army possessing it. The decisive effect of the absence or presence in the field of preponderating weight of metal, was strikingly shown last year by that of the two 18-pounders so opportunely brought up by the English at Inkermann.

The general advantage, then, of increased caliber in field-batteries does not seem questioned; but with every increase of caliber, a train of consequences requires consideration. The weight of ammunition; the strength and weight of gun-carriages and ammunition boxes, &c.; the horse-power for transport, and perhaps the number of men per gun, must all be increased, but still faster, probably, in the ratio of D^3 to D.

The weight of *shot alone must* increase in this ratio; but it is far from certain that the weight of powder must, for the experiments or propositions made by Brittan, the author, Whitworth, and others, on elongated "running shot," with closed windage, prove that it is quite practicable to obtain, with equal weight of such shot, equal ranges to round shot, with charges of one-third, or even less, of established service charges; but elongated shot, with small windage, by which alone this important economy in cost for expenditure and transport of powder can be realized, demands guns which shall be capable of withstanding, uninjured, the greatly increased local strain at the moment of explosion, and which bronze guns will not do; the increase of dimensions, and, therefore, as respects ammunition, of weight, and horse-power, would be reduced to what is needed for increased weight of shot only.

As at present constructed, *recoil* is met wholly by the inertia of the gun and of the gun-carriage; and if caliber be increased, these must be increased in mass to meet it; that is to say, in undisguised words, our means for absorbing or reducing the recoil remain of that primitive character, that we carry about with us—over whatever difficulties of country, or at whatever expense, or destruction of horse-power—a *quantity of dead weight,* not required to resist the explosion of the powder in its useful effects, but *merely to provide inertia* to bear its recoil. Now, it surely does not admit of contest, that recoil may be absorbed by elastic forces as well as by inertia,—by compression as well as by weight; and that elastic resistance may be increased as the caliber increases, without corresponding weight in the equipments. Nor can it be doubted, that practical ingenuity can devise the means of

connecting guns and gun-carriages, through the intervention of such compressible materials as shall admit of this being realized, without sacrifice of simplicity or effectiveness in the gun. If this be done, the gun-carriage need not seriously increase in weight; and if applied to wrought-iron guns, whose weight for equal caliber and equal strength shall be much under that of guns of bronze or cast-iron, as much weight may be saved in the gun as, added to the equipments, may leave the entire gun no heavier than at present, and yet give all that is demanded in resisting recoil.

The experiments given in the text indicate, that with guns much shorter than existing models, but with gun-cotton ammunition, equal ranges may be obtained; or, with elongated shot and equal charges, greater ranges; but to give resistance for such a mode of firing, wrought-iron is the only material fitted for the gun itself. Ultimately, then, we may look forward to the introduction of wrought-iron field-guns mounted on carriages constructed to receive and absorb the recoil by elasticity, instead of the old and barbarous expedient of mere weight, and adapted, in length and contour, to gun-cotton and elongated shot, with minimum windage, and of enlarged caliber,—perhaps all 18 or 24-pounders,—yet which shall have no greater element of difficulty in their transport or working, than shall be inevitable to the carriage of an increased total weight of shot; and even this weight would not increase quite in the ratio of D^3 to D over that for existing guns,—for the advantages in the field to be anticipated from such power would, no doubt, reduce the quantity of ammunition, or the number of rounds requisite for a given object, considerably.

The advantages in view would be, all those that the French field-train has already derived from the Emperor's reform, carried out and extended: the power of throwing shells and shrapnells of a size and weight to be really effective—the only point, perhaps, in which the French 12-pounders are found deficient,—increased range—increased accuracy of fire—and the capability of employing such field-guns, upon emergency, as effective instruments of demolition against places of strength, from the increased inertia of motion of their heavy shot.

Something might be set down, also, in favour of wrought-iron field-guns, to the small value of the material, and, as proposed being mounted, to their lightness and the facility of detachment from the gun-carriage, rendering dismounting and disabling the gun more rapid and complete, capture less valuable as well as less easy, and setting free an enormous capital, now laid up idly in the bronze guns of European powers.

The relative advantages and disadvantages of any projected change in field artillery involves so many contingent circumstances, each demanding separate and careful consideration, both as to its own effect and its relation to every other part of a complex system or machine, that the views thus attempted to be sketched within the limits of a Note must leave the subject most imperfectly treated, and liable to much objection. I would respectfully commend, however, to professional military readers, the primary idea, of the

practically carrying out the consequences of taking up recoil in field-guns, not by inertia, but by elasticity, as productive of future results, in connexion with wrought-iron guns and improved ammunition, likely to revolutionize our existing field artillery.

Note U.—(Sect. 270.)

The American Reports contain some interesting accounts of their methods of proving musket barrels by water pressure; but there are no systematic results as to the relation of resistance to fluid pressure from within, to diameter and thickness of metal.

The experiments of Lieut. Hagner, U. S. A., indicate that the best musket barrels will not sustain, without injury, a steady and continued water pressure of above 6400 to 6500 lbs. per square inch of internal surface; and, taking the section of resisting metal from the thinnest part of the barrel exposed to the pressure, the strain per square inch of section of wrought-iron due to this pressure is about 25,500 lbs. So that, even on these *thin* cylinders, the rupturing strain is much below that of direct tension, which, for the iron of these barrels (Salisbury, U. S.), is given at 66,000 lbs. per square inch.

Note V.—(Sect. 271.) See Note T.

Note W.—(Sect. 282.)

Resistance of Cylinders to Fluid Pressure from within.

For the following original investigation I am indebted to my learned friend, A. S. Hart, Esq., LL. D., Fellow of Trinity College, Dublin, whose attention was directed to this subject by my questioning the correctness of Professor Barlow's deductions from his own theory, and stating to him (though imperfectly and incompletely) my own views as to the effects of distance from the axis upon the effective resistance of any given lamina.

With his permission I place it in this Note, and gladly avail myself of the opportunity of acknowledging the advantages I have derived, on this and other subjects, from his great mathematical ability.

"The cylinder may be considered as consisting of a series of cylindrical laminæ, the inner of which is extended by the pressure of the fluid, part of which pressure is sustained by the resistance of the first lamina, and part transmitted to the next, and so on.

"If the cylinder be conceived divided by a plane, it is evident that the force which tends to separate its portions is proportional to the area of this plane, and is a maximum where the plane passes through the axis; and the same is evidently true of each of the cylindrical laminæ.

"Let ρ be the radius of any of these cylinders, and $2P$ the corresponding force, the length of the cylinder being unity. Also, let $\rho + \delta$ be the radius of the same cylinder when extended, then (according to the common theory),

$$\frac{dP}{d\rho} = -k\frac{\delta}{\rho}. \tag{1}$$

"Again, let two consecutive sides of the cylinder subtend at the axis, the angle θ, the portion of the lamina included between these sides sustains a pressure $P\theta$, and its original thickness having been $d\rho$, and its thickness under pressure $d\rho - d\delta$, we will have (according to theory)

$$P\theta = -k'\rho\theta\frac{d\delta}{d\rho}, \text{ or } P = -k'\rho\frac{d\delta}{d\rho}. \tag{2}$$

"Multiplying the sides of this equation by those of the preceding equation, we get

$$PdP = kk'\delta d\delta; \tag{3}$$

therefore,

$$P^2 = kk'(\delta^2 - \Delta^2),$$

(Δ being the value of δ at the outer surface of the cylinder, where $P = 0$); and eliminating P between the equations 2 and 3,

$$\frac{d\delta}{\sqrt{(\delta^2 - \Delta^2)}} = \sqrt{\frac{k}{k'}}\,\frac{d\rho}{\rho},$$

and, by integration,

$$\frac{\delta + \sqrt{(\delta^2 - \Delta^2)}}{\Delta} = \left(\frac{\rho}{R}\right)^{\sqrt{\frac{k}{k'}}}. \tag{4}$$

(R being the radius of the outer surface of the cylinder).

"But if r be the radius of the inner surface, and Π the pressure of the fluid on the unit of surface, the value of P for the inner surface will be Πr; and, substituting this value in equation 3, we have

$$\Pi^2 r^2 = kk'(\delta'^2 - \Delta^2) \tag{5}$$

(δ' being the value of δ at the inner surface); and eliminating Δ between equations 4 and 5, we get

$$\delta' = \frac{\Pi\rho}{\sqrt{kk'}} \cdot \frac{R^{2\sqrt{\frac{k}{k'}}} + r^{2\sqrt{\frac{k}{k'}}}}{R^{2\sqrt{\frac{k}{k'}}} - r^{2\sqrt{\frac{k}{k'}}}}; \tag{6}$$

and if m be the greatest value of $\frac{\delta}{r}$ which the metal can bear without fracture, we get for the corresponding pressure,

$$\Pi = m\sqrt{kk'} \cdot \frac{R^{2\sqrt{\frac{k}{k'}}} - r^{2\sqrt{\frac{k}{k'}}}}{R^{2\sqrt{\frac{k}{k'}}} + r^{2\sqrt{\frac{k}{k'}}}}. \tag{7}$$

"This conclusion depends upon the following admissions:—First, that the extending force bears a constant ratio k to the extension; secondly, that the compressing force bears a constant ratio k' to the compression; and, thirdly, that fracture only occurs when the extension has exceeded the limit m; but it remains still to be proved by experiment whether the resistance to extension is diminished or increased by simultaneous compression in a transverse direction, and *vice versa*. Judging from the fact, that the extension of a piece of India-rubber produces a visible compression in the transverse direction, and *vice versa*, it seems probable that the effect of either of these forces must diminish considerably the power to resist the other; and, if this be so, the resistance of the tube will be lessened; it is, also, conceivable that a very great compression might of itself produce fracture, i.e. disintegration, without any extension; or might (before reaching the crushing limit) make the material more easily broken by a transverse tension.

"Supposing these objections (which apply to all the common formulæ for strength of materials) can be disposed of, that $k = k'$, the expression for Π assumes a very simple form:—

$$\Pi = mk\frac{R^2 - r^2}{R^2 + r^2} \therefore \Pi < mk. \tag{8}$$

"As respects gun barrels, it should be remembered, that the transmission of the strain from the inner to the outer surface of a thick barrel occupies some time, which may, perhaps, be sufficient to make a sensible increase of strength, by retarding the entire effect until the ball has had time to leave the gun; and that this same cause may produce a great increase of the compression of the inner surface at the first instant of the shock.

"In estimating the strength of tubes, it is not necessary to consider the fact, that fracture usually takes place along one side first; it is *possible* that the opposite side may have precisely the same strength—in which case they might yield together.

"*On the Effect of Fluid Pressure upon the Tube.*—1°. Let the tube be supposed in its original state free from any strain; let r and R be the radii of its inner and outer surfaces, and let a pressure of F tons per square inch be applied to the inner surface: the effect of this pressure will be to extend the inner shell, and thereby cause it to press with a force F' on the shell next to it, and so on to the outer surface. Now, if x be the radius of the inner surface of any of these shells, and $x + dx$ the radius of its outer surface (the shell being supposed indefinitely thin), and if f, f' be the corresponding pressures, the internal

force on each unit of length of the tube, tending to split this shell into two semi-cylinders, is $2fx$, and the forces which resist this are $2f'(x+dx)$ plus the tenacity of the material. Let this latter force be supposed proportional to the extension, and let δ be the increase of the radius x produced by this extension; then, since the extension of the circumference, divided by the circumference, is equal to the extension of the radius, divided by the radius, the resistance at each extremity of the diameter, along which the tube is supposed to split, will be $k\frac{\delta}{x}dx$ (the value of k is immaterial, as it does not appear in the final result); and the condition of equilibrium will be

$$2fx = 2f'(x+dx) + 2k\frac{\delta}{x}dx;$$

or, if

$$fx = P, \quad f'(x+dx) = P + dP,$$

the equation becomes

$$dP + k\frac{\delta}{x}dx = 0. \tag{9}$$

" But it must be observed that this shell can only communicate pressure to the next one by virtue of its resistance to compression in the direction of the radius, and that this resistance may (according to the common theory) be assumed to be proportional to the compression, that is to say, since dx was the original thickness, and $d(x+\delta)$ the thickness under pressure, the resistance is proportional to $-\frac{d\delta}{dx}$; therefore, if k' be the exponent of this ratio,

$$f = \frac{P}{x} = -k'\frac{d\delta}{dx}. \tag{10}$$

" From these two equations P and δ are to be determined; multiplying them, we have $PdP = kk'\delta d\delta$, and integrating,

$$P^2 = kk'(\delta^2 - \Delta^2), \tag{11}$$

Δ being the value of δ at the surface, which is free from pressure. It is not necessary to suppose $k = k'$, but the calculation will be abridged by the supposition; and eliminating δ between (9) and (11), we have, on this supposition,

$$\frac{dP}{dx} + \frac{\sqrt{(P^2 + k^2\Delta^2)}}{x} = 0;$$

and, by integration,

$$\sqrt{(P^2 + k^2\Delta^2)} = P + \frac{x}{c},$$

(c being a constant introduced by integration). But since, when $x = P$, $P = 0$, the equation will, in that case, become

$$k\,\Delta = \frac{R}{c};$$

and, eliminating c by means of this equation, we find

$$P = \frac{k\,\Delta}{2}\left(\frac{R}{x} - \frac{x}{r}\right).$$

But when $x = r$, $P = Fr$, therefore $Fr = \dfrac{k\Delta}{2}\left(\dfrac{R}{r} - \dfrac{r}{R}\right)$, and eliminating $k\Delta$ between these equations,

$$P = Fr\,\frac{R^2 - x^2}{R^2 - r^2} \cdot \frac{r}{x}, \tag{12}$$

also,

$$\frac{k\delta}{x} = -\frac{dP}{dx} = F\,\frac{R^2 + x^2}{R^2 - r^2} \cdot \frac{r^2}{x^2};$$

and since this is the measure of the extending force on each square inch of the material, it must not exceed a certain limit, T; but it is evident that it is greatest when x is least, that is, when $x = r$; therefore the greatest pressure which this tube will bear is given by the equation,

$$T = F\frac{R^2 + r^2}{R^2 - r^2}, \quad \text{or} \quad F = T\frac{R^2 - r^2}{R^2 + r^2}.$$

"II°. Let it be supposed that the pressures of the different shells were originally so proportioned, that when the greatest internal pressure is applied, the tension $T = k\dfrac{\delta}{x}$ shall be uniform throughout the tube; then by equation (9) $dP + Tdx = 0$, and integrating

$$P = T(R - x), \tag{13}$$

and the internal pressure $F = \dfrac{T}{r}(R - r)$ is greater than the pressure corresponding to the same tension in the first case, in the ratio of $R^2 + r^2 : Rr + r^2$.

"III°. To find the original distribution of pressure which leads to this result, we must suppose the internal pressure F removed, or (which is the same thing) apply a pressure

$$-F = -T\frac{R - r}{r}.$$

Then, by equation (12), if p be the resulting value of P at any other surface whose radius is x, we have

$$p = - T(R-r)\frac{R^2-x^2}{R^2-r^2} \cdot \frac{r}{x} = - T\frac{R^2-x^2}{R+r} \cdot \frac{r}{x};$$

and uniting this with the value of P, given in equation (13), we have the original condition,

$$P = T(R-x)\frac{x-r}{R+r} \cdot \frac{R}{x}. \tag{14}$$

"IV°. To find the pressure on each shell during the construction of the tube, before the outer shells have been put on, we must suppose the pressure $= 0$ at the outer surface of the shell last put on, whose radius we may represent by y; therefore, we must apply at this surface a pressure, such that

$$p = - T(R-y)\frac{y-r}{R+r} \cdot \frac{R}{y},$$

to counteract that given by equation (14), and we must suppose the pressure $= 0$, as before, when $x = r$; then substituting, in equation (12), y for r and r for R, and the above value of P for Fr, we have

$$p = - T(R-y)\frac{y-r}{R+r} \cdot \frac{R}{y}, \ \frac{r^2-x^2}{r^2-y^2} \cdot \frac{y}{x} = + T\frac{(R-y)\,R\,(r^2-x^2)}{(R+r)(r+y)\,x},$$

and, uniting this with the value given in equation (14),

$$P = T\frac{R\,(x-r)\,(y-x)}{x\,(r+y)}, \tag{15}$$

and

$$\frac{k\delta}{x} = -\frac{dP}{dx} = T\frac{R\,(x^2-ry)}{x^2\,(r+y)}. \tag{16}$$

"The practical construction of a tube on these principles is immediately derived from equations (13) and (16). Thus, if it be required to construct a tube capable of sustaining a pressure double of the tenacity due to the material, we must make $F = 2T$, or $R - r = 2r$; that is, the thickness of the tube must be equal to its internal diameter, and, in order to produce the required pressures on the successive shells of which the tube consists (the number of which theoretically should be infinite) it would, perhaps, practically be sufficient to divide the thickness into four (or a greater number) of equal parts. In this case, if the inner radius be r, the outer radius of the first shell would be $\frac{3}{2}r$, of the second $\frac{2}{r}$, of the third $\frac{5}{2}r$, and of the fourth $3r = R$. Then, to find the mean tension of the second shell, when first put into its place, and before it has been enveloped by the third, we must substitute, in equation (16), the values $R = 3r$, $y = 2r$, $x = \frac{7}{4}r$;

whence the mean tension

$$k\frac{\delta}{x} = \frac{3\left(\frac{49}{16} - 2\right)}{\frac{49}{16} \times 3} T = \frac{17}{49} T.$$

In like manner, for the third shell, we have

$$y = \frac{5}{2} r \cdot x = \frac{9}{4} r,$$

and its tension

$$k\frac{\delta}{x} = \frac{82}{189} T;$$

and for the tension of the fourth, or outer shell,

$$k\frac{\delta}{x} = \frac{219}{484} T.$$

The total thickness of the tube in this example is very great; but it *will sustain a pressure more than double of that which would burst the thickest tube that can be constructed in one piece of the same material,* provided the calculated distribution of pressure be not altered by inequalities of temperature when the tube is in use; for it is evident that if the inner surface be made very much hotter than the outer, the original inequality of pressure will be thereby increased; and this might be extended so as to split the outer surface without the application of any other force from within." While, on the other hand, any required inequality of temperature may be allowed for in the first instance in proportioning the successive tensions of the shells or rings, a thing impossible in a tube constructed in one solid piece.

Again, if an example be taken of a cylinder sustaining a pressure of 6 tons per square inch, and that the maximum strain on the metal shall not exceed 8 tons per square inch, the requisite thickness will be $R - r = \frac{3}{4} r$; and let this be divided into four concentric rings, each of the thickness $\frac{3}{16} r$; then, before any pressure is applied from within, the tensions should be—

Of the outer ring . . .	1·840 tons per square inch,
Of the second ring . . .	0·937 ,, ,,

and the compressions of the two other rings—

Of the third ring, . . .	0·366 tons per square inch,
Of the inner ring, . . .	2·410 ,, ,,

But for the purposes of construction it is necessary to compute what the strain on the two

inner rings is before the third is put on, and, again, what the strain on the third is before the outer one is put upon it. These are found to be—

The strain of the second ring upon the first, ...	0·93 tons per square inch,		
,, of the third ring upon the first and second, .	1·49	,,	,,
,, of the fourth ring upon the three inner ones,	1·84	,,	,,

Let it be assumed that a strain of one ton per square inch results from a difference of temperature of 16° Fahr. in a thin hoop, placed hot upon a solid cylinder of cold cast-iron, then if the thickness of two superimposed rings be the same, it is obvious that the inner one will be compressed, as much as the outer one is extended. The strain on each, therefore, will only be half a ton per square inch. So that the difference in temperature at the moment of superposition of the first and second rings should be 29°·76 Fahr., and the same difference of temperature would very nearly answer for each of the other rings, which results in the simple rule, that each ring should be put on at a temperature of 30° above that of the preceding ones.

The larger the diameter of the gun, the less injuriously will it be affected, upon this construction, by the inequality of temperature produced by firing hot shot or by quick firing. If a greater maximum pressure per square inch than that above taken be demanded, and that still the maximum strain upon the metal shall not exceed 8 tons per square inch, the increased thickness is readily found. If it be 20 tons pressure per square inch, the thickness must be $= 2{\cdot}5r$; if 40 tons, $= 5r$; and soforth—the temperatures of the successive rings being calculated as before.

The latter part of the preceding calculations, it will be observed, proceeds upon the conception that the physical conditions of the metal of the cylinder (iron) are such as to give rise to a strain of 1 ton per square inch for every 16° Fahr. difference of temperature, in accordance with the books of physical writers (e. g. Dixon on Heat, sec. 85). The error of this conception has been pointed out in the text, as well as the extreme facilities of practically fulfilling all the requisite conditions of theory, in cylinders thus built up, which the actual physical constitution of wrought-iron confers. In fact, its ready power to become stretched, at temperatures above a bright-red heat, at once avoids all difficulty as to the precise temperature at which each ring is to be superimposed, and as to mathematical precision in their respective diameters. The process in practice with rings varying from 36 inches up to more than 70 inches diameter, and of various thicknesses, from 2 inches upwards, and of different widths, from 24 inches down to 4 inches, has, in fact, been actually found to be attended with as little difficulty as the shrinking-on of the tyre of a railway wheel.

NOTE X.—(SECT. 286.) See Notes K. and W.

NOTE Y.—(SECT. 289.) See Note W.

NOTE Z.—(SECT. 305.)

I REPRINT the following two Reports nearly *in extenso*, not for anything of value which they convey, but to demonstrate three things:—

1°. How little real knowledge and competent judgment have yet been brought to bear, even from "authority," on the question of the advantageousness, or the contrary, of wrought-iron guns, as applicable to present times.

2°. To enable presumedly competent parties, who were decidedly hostile in view, to state fully all they were able to advance against the adoption of wrought-iron guns, in order that my readers may fairly judge, one of the main questions I have treated, having both sides before them.

3°. To corroborate, by the facts of these Reports, the statements of the text, as to the reality and magnitude of the difficulties inseparable from every attempt to construct wrought-iron ordnance by welding up into heavy single solid masses.

"UNITED STATES GOVERNMENT.

"*Bureau of Ordnance and Hydrography,*
"*April* 2, 1844.

"SIR,—In reply to your letter of the 28th ult., transmitting a call from the House of Representatives, for information respecting the strength, utility, and cost of wrought-iron cannon, and the result of the experience of European powers on the subject, which may be in the possession of this Bureau, I have the honour to submit the accompanying papers, marked from Nos. 1 to 4, viz.:—

"No. 1. Captain R. F. Stockton's Report of his gun practice, with his wrought-iron gun, at Sandyhook.

"No. 2. Report of inspection of the first gun, by Commodore Wadsworth.

"No. 3. Captain Stockton's Report of proof of gun.

"No. 4. The cost of each of the wrought-iron guns, made under the superintendence of Captain Stockton, so far as paid for by this Bureau.

"Our information in regard to wrought-iron cannon is very scanty. Tonsard tells us, in a note to page 190, volume first, 'Artillerist's Companion,' that 'in 1776 an iron gun was forged by Mr. Samuel Wheeler, an eminent artist, still living (1809) in the city of Phila-

delphia. It was intended, at first, as a 4-pounder, but was only bored for a 3-pounder. This gun was taken at the Battle of Brandywine, and is said to be now in the Tower of London.' I believe this is the only gun of which we have any record in this country, as having been used in actual warfare, and, as it appears, with success. The next account of the manufacture and proof of wrought-iron guns in this country is found in the Report of a Board of Officers of the Army, as follows:—

"'A 6-pounder wrought-iron gun, manufactured by R. and S. Hunt, anchor makers, was tried at Watervliet Arsenal, in 1832. This gun was fired two proof charges, and forty rounds service charges. At the eighteenth fire the band which held the trunnions slipped off, and had to be replaced. After the forty rounds, the gun still remained serviceable. The greatest enlargement of the bore was found to be 0·04 inches, which is more than double that of any of the brass guns proved lately; from which we may infer, that if all difficulties were overcome, and a complete iron gun made, it would have no great advantage over bronze, as regards its durability. It is understood that these same manufacturers failed in making other wrought-iron guns.

"'Although a proof-gun can be made when the metal is selected with great care, and the fabrication carefully watched, yet, in fabricating them on a large scale, it will be impossible to take the precautions necessary to insure the perfectness of all these numerous welds. The smallest crack would contain moisture, which would produce oxidation; and this would, in time, destroy the gun. The Board do not think it necessary to incur further expense in testing this material.'

"Again, says this Report—'Guns of this material (wrought-iron) were the first used, and they have been tried at various periods, since the first invention of gunpowder, and always without success.

"'The first and greatest objection is the difficulty of welding the parts together perfectly, and the still greater difficulty of determining whether the welds are perfect or not. In the account of a wrought-iron gun, tried at Toulon in 1795, it is stated, that after the gun was broken up, the cascabel and trunnions were found to be held only by a portion of the faces which touched. Three-fourths of these faces showed the effects of rust.'

"It appears from most authorities that the art of casting guns was esteemed a great improvement upon the more ancient art of forging them, and, whatever may have been the cause, immediately superseded the latter. The cause may have been the vastly diminished cost of the cast-iron guns, or the facility of manufacture, or the opinion of greater security and certainty in the use; or, probably, the combination of all these. Certain it is that the forged guns went entirely out of use. (For the true causes of this, and correct dates of the change, see Note B.)

"Several accounts of these forged iron guns are given by writers on artillery. Tonsard says, page 168, vol. i.—'There are at present (1809) on the ramparts of Narbonne two

old pieces, composed of iron bars, applied lengthwise, and encircled with strong iron hoops transversely, the whole soldered together. They are not much altered, although they have been neglected for a long time; but the rust has injured them most in the points of junction, and made these more apparent. It is probable that if, at the time when they were made, the arts had been as far advanced as they are at present, they would still be fit for service.

"'New attempts have lately been made in France, at Guerigny, Department de la Nievre, and in Spain, at Cevada, New Castile, to construct such guns, and they have been crowned with success. But at first, when compared with cast-iron guns, wrought-iron heavy ordnance would have been attended with considerable expense, as well from the price of metal as from the attention which their fabrication requires; and secondly, the enormous consumption and want of cannon at that time (1794) compelled a recurrence to the most expeditious and least expensive proceedings—therefore, to confine their fabrication to cast-iron. However, they (i. e., wrought-iron) are not half as expensive as brass guns.'

"It may be remarked here, that Tonsard was strongly in favour of experimenting upon wrought-iron cannon, with a view to their introduction into the service of the country. He observes, however, of cast-iron, 'that if it was by some means possible to produce a more perfect melting of the iron, cannon cast of this metal, with an equal thickness, would be stronger, more durable, and lighter than brass cannon,' page 198. He gives the preference, however, to brass cannon, because these are they 'the service of which should present most security.'

"Grose, in his 'Military Antiquities,' vol. i., page 381, says, that cannon 'were, in general, constructed of iron bars soldered, or welded, together, and strengthened with iron hoops; others were made of plates of iron rolled up, and fortified with iron hoops.' He speaks of several 'at Woolwich, one belonging to —— Pooley, Esq., in Suffolk;' and 'also several of those hooped guns in the Isle of Man, England.' Bombards were at first chiefly made of hammered iron; but, in process of time, many were cast of that composition named bell or gun-metal. They were also sometimes made of plates of iron and copper, with lead run between them. One of these guns was taken up on the coast of Ireland.

"That wrought-iron guns, constructed of iron bars hooped together, were used very generally, we know from the specimens yet preserved, and the facts of history. James II. of Scotland lost his life before Roxburgh Castle, by the bursting of one of these guns. In 1545, a man-of-war, named the 'Mary Rose,' commanded by Sir George Carew, sunk off the Isle of Wight, with her whole crew. Three hundred years, nearly, after the accident, Mr. Dean, with his diving apparatus, raised a 24-pounder brass gun, and, at the same time, some iron guns. The iron guns were formed of iron bars, hooped together with iron rings, and they were all loaded, &c.—*Wilkinson's Engines of War.*

"'In 1813, an engineering company of Lyons, named the St. Etienne Company, proposed to the French Government to manufacture all the guns then wanted of forged iron. They sent to Paris a specimen 8-pounder, weighing 570 lbs. It was mounted upon a truck-carriage, with solid wheels, 17 inches in diameter, and fired with 3 lbs. of powder. The recoil was 25 feet; with 4 lbs. of powder it was 37 feet. The gun sustained nine rounds without injury; but the material was not approved of by the French officers. Other pieces, of the caliber of 16 and 24, were made; the mode of fabrication seemed to be this:—Upon a tube, formed after the manner of a common fowling-piece, or gun-barrel, bands of iron were welded, embracing the tube, but in a direction contrary to that of the fibres of the tube, until the requisite size and strength were obtained. The gun was bored out to the proper caliber, and the breech-piece screwed in and soldered to its place by silver solder, which was esteemed the best. The different bands of iron were welded to each other, and to the tube, by blows from the hand-hammer.

"'The inventor proposed to employ, in the fabrication of 24-pounders, &c., bars of iron 12 feet long by 1 foot 8 inches, which, forged out into skelps, and converted into bars thinned off at the side, were welded together over a maundrel, under blows of a trip-hammer. The trunnions were welded to one of the (external?) bands. The bars used were twisted; and they believed that, as the small arms manufactured were excellent, this process augmented the tenacity of the metal by a fourth; and this was their secret.'

"But, extending the manufacture on a great scale, could we hope that the metal shall always be scrupulously chosen, and that a practised and observing eye shall always watch over the degree of heat which the metal ought to have, in order to work to a uniform solidity the prodigious quantity of welding necessary to perfect the piece? When the gun is fired, the imperfect weldings will open imperceptibly, and the damps will penetrate the fissures, which, after a time, will cause the gun to crack, and form within the bore leafy exfoliations, which, retaining the fire, will occasion accidents. In short, the irremediable oxidation of the bore, in time of war, will so enlarge it, as to throw the piece out of service; and in time of peace they would require constant painting to prevent this oxidation."

The objections to wrought-iron guns are continued thus:—

"1st. They promptly destroy the carriages by the suddenness and extent of the recoil.

"2nd. They incommode greatly the troops by the length of the recoil.

"3rd. They will change their range greatly, by the continued and inevitable oxidation of the bore.

"4th. They enfeeble the 'moral' of the cannonier, by the continued apprehension of their bursting.

"'In fact, these guns often burst, although the first pieces furnished by the Company did not always burst. We have thus dealt at large upon the defects of wrought-iron guns,

in order to reply, once for all, to the pretensions of an invention which claims to be good, and is often represented as new.'—*Aide Memoire*, vol. ii. p. 784, &c. Paris, 1819.

"Some of the Spanish writers speak of wrought-iron guns. Thus, Ciscar, in his 'Tradada de Artilleria,' Madrid, 1829, says:—'We do not owe the information that wrought-iron cannon of all descriptions formerly existed, to the Chevalier d'Arcy alone, but also to many writers. Texier de Norbec, amongst others, treated at length of various guns of this kind. From 1666 to 1694, there was one in the Arsenal of Zurich, in Switzerland, of 24 lbs. caliber, the constituent parts of which admitted of being dismounted and replaced at pleasure.'

"'In the Arsenal of Paris are found two pieces—one a 16, and one an 8-pounder, constructed of tubes, one within the other, secured by strong bands, and the whole welded together; and I am assured that we have in our own establishments two wrought-iron guns, light, and of perfect workmanship.'

"'At the Chateau of St. Dizier, a very old piece was found, of a caliber of 20 inches, and weighing 7616 lbs. The chase was made of wrought-iron, and the chamber and breech cast of the same metal. At Harty, also, were some pieces, 12 or 16-pounders, of wrought-iron, which do not appear to have been fabricated in the usual manner, with bars, and banded, welded together; nor is the process known. They weigh about 8000 lbs.'

"Again—'At Brest is a cannon taken from the English, weighing 7723 lbs., 11 ft. 1 in. long, and of 6 in. caliber. The bore is made of seven bars of wrought-iron, secured by bands of the same metal.'—*Aide Memoire*, vol. ii. p. 784.

"It appears that wrought-iron guns have been made from the earliest times, and were, until superseded by the introduction of cast-iron and bronze cannon, the principal artillery in use; that at different periods since the general use of cast guns, efforts to construct serviceable cannon of wrought-iron have been made by the principal European powers, and that, whatever may have been the cause, they have not been again employed in active warfare. The inference is, therefore, although no further information than the foregoing is in the possession of this Bureau, that they have not been used, for good and sufficient reasons.

"The two wrought-iron guns on board the steamer 'Princeton,' being the only guns of that description ever used in the Navy, no opportunity has been afforded this Bureau of ascertaining the relative strength and utility of wrought and of cast-iron cannon.

"All of which is respectfully submitted.

"I have the honour to be, very respectfully, Sir,

"Your obedient servant,

"W. M. CRANE.

"*Hon. John Y. Mason, Secretary of the Navy,*
Washington."

Extracts from the Report of the Committee on Naval Affairs, to whom were referred certain communications from the War and Navy Department, on the subject of large Wrought-Iron Guns; and, in pursuance of the duty assigned them by the House of Representatives, submit the following Report:—

"*Ordnance Office, Washington, April* 5*th*, 1844.

"SIR,—In reply to the resolution of the House of Representatives, calling for information as to what experiments have been made by officers of the War Department, for the purpose of testing the strength and utility of cannon manufactured from wrought-iron; specifying such particulars as may tend to show the relative strength and utility of wrought and cast-iron cannon, together with copies of all Reports from ordnance or other officers on this subject, and such other information connected therewith as may be considered useful; as also the experience of European powers on this subject; and particularly the largest size to which wrought-iron cannon for solid shot have been carried with success; and likewise the expenses of the experiments, and to whom the money was paid: I have the honour to report—That *the only experiments for the purpose of testing wrought-iron guns recorded as having been made by this Department, are, the trial of two* 6*-pounder guns at Washington and Watervleit Arsenals, in* 1832, *and the experiments now in progress, but not completed, at Fort Monroe Arsenal, with some guns of the same caliber.*

"In the experiment at Watervleit Arsenal, the gun was fired twice with a proof charge, and forty times with service charges.

"The band which held the trunnions slipped off at the eighteenth round, and the firing had to be stopped to replace it. After firing the forty-two rounds, the gun remained serviceable, but the enlargement of the bore was found to be as much as ·04 inch, which is more than double that of the bronze guns now made. This enlargement of the bore is the greatest objection to bronze artillery, and would soon render a gun unserviceable; and, so far as this experiment goes, it tends to prove that wrought-iron has no advantage over bronze in this respect, and, consequently, no greater durability. The particulars of this experiment, and of the mode of manufacture pursued in this instance, will be found in the Report of Major Talcott, and the accompanying statement of the manufacturer, copies of which are enclosed herewith.

"The trial at Washington Arsenal consisted only in firing proof charges, which left the bore of the piece in a condition unfit for service, by opening the seams, or welds.

"By direction of the Secretary of War, some 6-pounder guns have been manufactured, in 1843, according to a new method, which is not divulged, at the same price as bronze guns, and promising to unite the advantages of wrought with those of cast-iron. These guns are now at Fort Monroe Arsenal, where experiments to test their strength and durability are now in progress. They are not, however, completed; and, although of those

tried, one failed at the 150th fire, by the trunnion band becoming loose, and another, at the 450th fire, by the opening of the welds, the results, so far, are not sufficient to warrant a definite conclusion as to the merits of this mode of fabrication. So far as it has been tested by this Department, wrought-iron has not proved a good material for the manufacture of field-guns ; and as the difficulty of fabrication increases with a greater quantity of metal, it is less suitable for those of a larger caliber. The greatest objection, and apparently an insurmountable one, is the difficulty of welding the parts together perfectly, and the still greater difficulty or impossibility of ascertaining whether the welds are perfect or not. Besides, the effect of heating is to render the iron more porous, and of less specific gravity and tenacity ; and, when often repeated, is known to destroy the good qualities of the best refined iron. When the bars are of small size, as in gun-barrels, the hammering compresses and re-unites the particles, and corrects these defects ; but in large masses the effects of the hammer do not reach the interior of the mass, which is, consequently, left open and spongy, although the metal on the surface, and to a slight depth, is compact and fibrous.

" The objects attempted to be gained by the use of wrought-iron for cannon are— 1st, lightness; and 2nd, strength.

" 1st.—Reasoning from the successful use of that material for small arms, it has been supposed that a skilful and careful fabrication would effect these results. But lightness, below a certain ratio, is not desirable ; it is positively injurious, for light guns can be used only with light charges. Field-guns cannot be conveniently served when they have less than 150 lbs. of metal to each pound of shot ; and battering-guns require at least 200 lbs. of metal to each pound of the shot. With any less weight, the service of the gun is very difficult, from its excessive recoil ; therefore, lightness is not a desirable point in the construction of cannon[?].

" 2nd.—Strength. As this is always desirable, it should be effected if possible, but not at the expense of any other important point. If it were possible to fabricate sound and strong guns of wrought-iron, they would be found deficient in hardness. The projectiles used are of cast-iron, a material much harder than wrought-iron ; consequently, the wrought-iron gun is soon indented and worn so much as to prevent all accuracy in firing, and it then is worth little or nothing[?].

" Leaden balls are used in small arms, but they are inadmissible in cannon, as the great heat of the exploded gunpowder melts the lead more or less, and changes the form of the ball, thereby reducing its range. Besides, lead has not sufficient tenacity to enter hard substances, and therefore is not a suitable material to be used against ships and batteries. Wrought-iron is also more liable to injury from rust, than bronze or cast-iron ; and the smallest crack, admitting moisture, would, of itself, in time, seriously injure the gun. The

first-cost of wrought-iron cannon is the same as that of bronze[?], and more than six times that of cast-iron. Bronze guns, it may be further remarked, after being too much worn for service, can be easily recast, whereas the old wrought-iron is useless for refabrication, and of little value in such large masses for any purpose.

" In regard to the experience of European powers on this subject, it may be stated generally, that the use of wrought-iron, as a material for cannon, has been attempted in Europe repeatedly, without success, from the invention of fire-arms to this time. The cannon of small size have succeeded better than large ones; indeed, there is no known record of a wrought-iron gun for heavy shot proving satisfactory[?]. The works of European writers on artillery abound in notices of wrought-iron cannon, of dates of manufacture extending back from the present century to the remotest periods of their use.

" Frequent instances of accidents from their bursting are mentioned, and they have never been successfully manufactured on a large scale. Meyer, in his work entitled, 'Experiments in the Fabrication and Durability of Cannon, both Iron and Bronze,' edition of 1834, says :—' It is certain no experiment in artillery has been so often unsuccessfully repeated and abandoned as the fabrication of wrought-iron cannon ; and even at this time we are but little further advanced in it than at the beginning.' And Gassendi, in his ' Aide Memoire d'Artillerie,' edition of 1819, condemns the use of wrought-iron for the manufacture of cannon entirely. Herewith are submitted extracts from different writers, containing a chronological history of wrought-iron cannon, and remarks on the use of this material for their fabrication."

These extracts are omitted, as a much more complete chronology of the subject is contained in Notes A and B.

" In regard to ' the relative strength and utility of wrought-iron and cast-iron cannon,' the former having been already noticed, it may be stated, in reference to the latter—

" First,—As to the strength. Cast-iron is of so many different qualities and kinds, and so variously affected by different modes of fabrication, that it is impossible to speak of the strength of cast-iron guns *generally*. It is known, however, that by careful attention to the selection of the metal, to its treatment in the furnace, to its proper distribution throughout the body of the gun, in relation to the force exerted on its different parts, by the discharge, to its gradual cooling after being run into the moulds—in a word, to all the manipulations connected with its manufacture, and not so severe a proof, as to strain or weaken the cohesion of the particles, cast-iron guns, sufficiently light for siege, sea-coast, and garrison service, may be made, the use of which, with full charges, will be safe for at least one thousand fires. But although the practicability of making good and safe guns of cast-iron

is believed to be an established point, it must be admitted that it requires a constant supervision and vigilance, which can only be obtained by means of a foundry under the entire control of the Government, or the employment of a skilful practical officer, to attend at the private foundries during the whole process of fabrication."

The latter appears to be the arrangement in habitual use up to the present time, in procuring, by contract, the United States ordnance.

"Secondly,—As to utility. In former times, it was supposed that bronze only was suited for heavy guns, both on sea and land; and it was only after great advances had been made in the arts, that the maritime powers of Europe ventured to use cast-iron guns on board their ships."

We might have supposed that this would have suggested the likelihood of a similar career for wrought-iron.

"The less cost and greater hardness of cast-iron, therefore, have led to its use for artillery; and when it is considered that six or seven cannon of this material can be procured for the same cost as one of bronze or wrought-iron, it will readily be perceived, that, if we can fabricate them in such a manner as to render them safe for only one thousand fires, they should be adopted on the score of economy, and their accuracy of fire up to the period of their being laid aside. Accordingly all the European powers have fabricated their heavy guns for ships and batteries of this material, using bronze only for field and siege-trains.

"The British troops in the Peninsular war on several occasions found their siege-trains of bronze speedily rendered unserviceable, and resorted to cast-iron guns; the superiority of which over bronze consisted in their greater accuracy, and being less heated in rapid firing, and they are stated to have endured 2700 discharges at St. Sebastian. 'These pieces had preserved such accuracy of fire, that in the last days of the siege, they were fired from a great distance, over the heads of the besiegers at the breach, with sufficient precision to reach the besieged behind a high rampart.'

"The expenses of the experiments in wrought-iron cannon made at Watervleit and Washington Arsenals, consist only in the cost of the ammunition used in firing them, which was taken from that on hand at those Arsenals. Nothing was paid for the guns. For the experiments now in progress at Fort Monroe Arsenal, the expenses consist of the cost of the necessary ammunition, prepared at the Arsenal, and the price of the guns

(2100 dollars), which has been paid to the manufacturer, Mr. Daniel Treadwell, of Massachusetts.

"The resolution of the House of Representatives is herewith returned.

"I am, Sir, very respectfully, your obedient servant,

"G. TALCOTT, *Lieut.-Col. Ordn.*

"*Hon. William Wilkins, Secretary of War,*
"*Washington.*"

It is not unworthy of remark, that the United States Ordnance, which has really done more to advance *experimentally* the art of manufacturing cannon than all the European services together, possesses no Government establishments for gun-founding, boring, &c., whatever; and one of its most distinguished officers, long employed in the personal superintendence of the execution of Government contracts for ordnance, in private foundries, voluntarily bears testimony to "the improvement in the quality of cannon, which has been greatly assisted by the proprietors of the foundries at which the experiments were made." "Their practical knowledge of the qualities and treatment of iron, their suggestions, and zealous co-operation in all experiments made, and the liberality with which they provided all needful facilities for the purpose, have contributed most materially to the success which has attended these efforts to improve the strength and safety of cannon."—*Reports*, p. 277.

Can it be doubted that a like, or even a much higher result, would accrue from a really candid, liberal, and trustful resolve, to gather and apply to the improvements of our ordnance, all that vast accumulation of science and practical skill, which exists in the foundries and the engineering workshops of England, but which has so far been systematically repelled, and often, when volunteered with undeniable success, requited by the adoption, whole or in part, of the information or invention conferred, without that just acknowledgment which the enthusiastic improver covets above all things.

Nothing can be more judicious than the formation of those Government gun and other foundries, &c., recently set about, as the means (amongst other important ends) of enabling officers of the artillery and engineering corps to acquire that practical knowledge which existing methods of their education, with the habits and subsequent employments of service, render so deficient; but while ever the gates of our arsenals, or the interior of departments, are closed to civil visitants, and the experiments and processes conducted therein pretended to be held secret by "the custom of the service," and with an unworthy jealousy,—so long will "the improvements" of these departments be found far in the rear of those of private intelligence, enterprise, and science.

Secrecy in such matters can answer no end now-a-days but as a cloak to ignorance or

inactivity. It is useless; for universal experience has shown that no secret of the smallest value can be maintained within the walls of an arsenal for even six months after its value is ascertained. Can a secret military invention of any note or value be pointed to at this moment, as in the possession of any one power upon earth exclusively? Not one.

Ventilation and competition are the very life and spirit of all improvement; and, in place of such an antiquated system of pretended secrecy, nothing would so energize and make vital the progress of our military departments, and more especially of the ordnance, as the publication in some form of an official journal of its works, researches, and progress; and an annual distinct, detailed, systematic, and scientific Report to Parliament of all that has been brought forward (good or bad), whether by communication or importation, of invention, experiment, research, or discovery, within the department at home; and progress ascertained, of whatever sort, in the war departments of other countries abroad. Whatever of new light such publicity diffused, would be returned with tenfold intensity to its source, and need not preclude reserve and silence upon any point (should such possibly be ever found) upon which the national welfare would render secrecy for a time expedient.

France, which possesses at once the largest and most important military literature in Europe, and reckons amongst her military officers and engineers some of the brightest names that adorn the roll of science, is a proof of the value of such publicity—of the admission of the principle that *science has no secrets*, and that *its valuable applications can have none.* There the results of every improvement or invention—every massive research or train of experiment, whether at Metz or Toulon—appear speedily in print, and give a fresh vantage-ground in common to every working mind, whereon to attempt still further progress. How full of stimulus to the slothful—of hope and promise to the zealous and aspiring!—how sifting of the chaff from the grain, is such a system of *publicity!*

NOTE AA.—(SECT. 305.) See Note Q.

NOTE BB.—(SECT. 305.) See Note T.

NOTE CC.—(SECT. 316.) See Note W.

NOTE DD.—(SECT. 318.) See Note S.

NOTE EE.—(SECT. 320.)

THE following list (which might be greatly extended) of German literature, bearing upon our subject, may not be unacceptable:—

1.—*Saltpetre, Gunpowder, &c.*

Alison, G. Chr.—Der Engl. Büchsenmacher (u. Gewehrfabrikant). Od. gründl. Anweis. alle Arten von Gewehren, Büchsen, u. Pistolen, nebst Percussions-Sicherheitsschlössern u. übr. Zubehör, nach den neuesten Erfind. u. Verbesser. zu verfertigen. Nebst Belehrungen üb. die verschied. Arten, des Schiess-u. Knallpulvers. Nachrichten üb. die bedeutendsten Gewehrfabriken Europa's, u. dgl. m. Nach. d. Engl., bearb. u. mit mehr Franz u. Deutsch Erfind. u. Verbesser. vermehrt. Mit 103 Abbild. 8. Quedlinburg, 832. Basse.

Bottée u. Rissault.—Anweis. das Schiesspulver zu bereiten. Aus dem Franz, übers. von F. Wolf. Mit 19 Kpl. gr. 8. Berlin, 813. (Reimer.)

Meineke üb. das Schiesspulver. gr. 8. Halle, 814. Hendel.

Muncke, Geo. Wilh.—Ueber das Schiesspulver, seine 3 Bestandtheile, die Stärke u. die Art seiner Wirk. gr. 8. Marburg, 817. (Cassel), Krieger.

Meyer in Erdmann's Journal, xiv. 2, für technische u. ökonomische Chemie. Mit Kpftf. gr. 8. (Leipzig), Barth.

Prechtl, Joh. Jos.—Technologische Encyklopädie. 12r.

Renaud, B.—Prakt Anweis. zur Fabrikation des Schiesspulvers u. zur Bereit. seiner Bestandtheile. Ins Deutsche übertragen von J. F. Hartmann. gr. 8. Quedlinburg, 838. Basse.

Schauplatz, dess. 113 Bd.—A. u. d. T. Handb. der Pulverfabrikation. Nach den besten in-und ausländ. Hülfmitteln unter Beistand eines Artillerie-Officiers aus-gearb. v. ein. deutschen Teckniker. Mit 7 lith. (Halb.) Folio-Taf 8. Ebend, 841.

Salzer, Carl. Fr.—Versuche üb. das Schiesspulver, mit Beweis, wie die Kräfte des Pulvers erhöht, u. $\frac{9}{10}$ hievon erspart werden können. Mit 2 Abbild. gr. 8. Karlsruhe, 824. Müller.

2.—*Cast-steel Manufacture.*

Haussner, Geo.—Die Kunst Gussstahl, u. Gusseisen, auf Schmiedeisen zu schweissen. Für Eisenwerke, Mechaniker, u. Eisenarbeiter. Aus der Schlosserzeitung abgedr. Leipzig, 843. Schmaltz.

Stahl-hütte, Schisshyttan in Schweden (Sefströmm in Erdmann's Journal, iv. 1).

3.—*Iron Manufacture.*

Erzeugung in Deutschland.

Hasse, Traug.—Die Eisenerzeugung Deutschlands aus dem Gesichtspunke der Staatswirthschaft betrachtet. Nebst Angabe der Ursachen ihrer Verminder. u. einigen Vorschlägen zur Vermehr. derselben. Ein Versuch. gr. 8. Leipzig, 836. Rein.

4.—*Cast-iron; its Strength, &c.*

Gusswaaren der Kurfürstl-Hessischen Eisenhütte zu Veckerhagen. (9½ lith. B. mit viel Abbildgn. u. Titelvign.). gr. 8. Cassel, 834. Bohné.

Meyer, in Erdmann's Journal, vii. 2.

5.—*Swedish Smelting Works.*

Winckler, in Erdmann's Journal, v. 4.

Winckler, in Erdmann's Journal, iii. 1.

6.—*Manufacture of Steel.*

Achates.—Aus allem Eisen Stahl zu machen. 8. Nürnburg, 761. Riegel.

Altmütter, in Jahrbücher d. Polytechn. Instituts von Prechtl. 12 Bd.

Cancrin.—Von der Zubereit. des Roheisens in Schmiedeeisen, auch des Stahleisens in Stahl. 8. Marburg, 790. (Cassel, Krieger.)

Damemme.—Prakt. Handb. der. Fabrikation u. Bearbeit. des Stahls. Nach d. Franz. Deutsch bearb. von J. F. Hartmann. Mit 10 Taf. Abbildgn. (in 4). 8. Quedlinburg, 839. Basse.

Ehrenberg, B. A.—Hülfsbüchl für Stahlarbeiter. 8. Essen, 826. Bädeker.

Hagen, T. Ph. v. der.—Beschreib der Kalkbrüche bei Rüdersdorf, der Stadt Neustadt-Eberswalde, u. der Finnow-Canals, wie auch der dasigen Stahl u. Eisen-Fabrik, des Messingwerkes, u. Kupfershammers. Mit vielen Kpf. 4. Berlin, 785. Reimer.

Halle, Joh. Sam.—Prakt Anweis. alle Stahlarten zu kennen, zu härten, anzulassen u. vernunftig zu bearbeiten. nach Perrets Preisschr. 8. Berlin, 783. Maurer.

Hartmann, Carl. Fried.—Lehrb. der Eisenhüttenkunde, 2te Abth. Die Lehre von dem Umschmelzen des Roheisens, u. von Verwend. desselben zur Giesserei, desgl. die von der Stabeisen u. der Stahl-bereit enthaltend. Mit 10 Kpfl. (in qu. gr. Fol.). gr. 8. Ebend, 834.

Leuchs, J. C. — Samml. neuer Abhandgn. üb. Eisen-Stahlbereitung. Mit Abbild verschied. Hochöfen, Schneid-Walz—u. Streckwerke. Mit 1 Steintf. u. 8 Holzschn. gr. 8. Ebend, 827.

Loof, Jams. — Geheimes Kunst-Cabinet für Metall-arbieter u. Fabrikanten oder die wichtigsten neuesten Engl., Franz. u. Deutsch Entdeckgn. u. Erfindgn. in der Kunst, in Gold, Silber, Stahl, Messing, Kupfer, Zinn, Eisen, Blech, &c., auf das geschmackvollste u. vortheilhafteste zu arbeiten, u. die verscheidenen Metalle auf das Beste zu den mannigfältigen Gegenständen zu behandeln. Aus d. Engl. A. u. d. Tit. Die Kunst, Eisen u. Stahl nach engl. Methode zu härten, engl. Guss-stahl u. Feilen zu verfertigen. Für Metall-arbeiter u. Fabrikanten. Aus d. Engl. 8. Quedlinburg, 828. Basse.

Neue, wichtige, u. sehr nützliche Mittheilungen für Eisengewerke, Eisen-u. Stahlarbeiter, Instrumentmacher, &c. (Von Joh. Gütle). 4. Ebend, 830. (Ebend), Verklebt.

Overmann, Fr.—üb. das Frischen des Roheisens, nebst Anweis. Stabeisen u. Stahl von bester Qualität aus den verschiedenartigsten Erzen zu erzeugen, u. auf die wohlfeilste Art zu gewinnen. Nach vielfältigen prakt. Erfahrgn. dargestellt. Mit 10 (lith.) Kpft. gr. 8. Brünn, 838. (Winiker.)

Perret.—Abhandl. von Stahl, dessen Beschaffenheit, Verarbeit. u. Gebrauch. Aus. d. Franz. v. J. H. Pfingsten. Mit 1 Kpf. 8. Dresden, 780. Walther.

Prechtl, in d. Journal 1r.

Rackebrandt, Aug.—Gründl. Anweis. das Platin zu reinigen u. zu verarbeiten sowie Mannheimer Gold (Semilor), u. engl. Cement-stahl zu fabriciren. Für Gold u. Silberarbeiter, Juweliere, Mechaniker, Gelbgiesser, Stahlarbeiter, u. and. Künstler. Mit 4 (lith.) Taf. Abbild. (in 4). 8. Quedlinburg, 838. Basse.

Rinmann, S. — Unterricht von Poliren des Stahls u. Eisens. 8. Flensburg, 787. Korte.

Schauplatz, 50 Bd.—Der Schlossermeister, od. theoret. prakt. Handb. der Schlosserkunst. Nach d. Franz. Werke des Grafen v. Grandprè für Deutsche Schlosser bearbeitete, sorgfältig revid.; 4 Aufl.; worin alle Beiträge, Verbessergn., u. Zusätze von J. G. Petri, C. H. Schmidt, Fr. A. Reimann, J. G. Buch u. F. Rathel, vollständ. berücksichtigt u. eine grosse Anzahl neuer Gegenstände u. Abbildgn. hinzugekommen ist. Mit 22 Steindrtf. (in qu ½ Fol.). 8. Ebend, (830), 843.

Verbesserungen u. Erfindgn., 100 neue, in der Bereit. des Eisens u. Stahls u. der Eisenwaaren. Auch als Nachtrag zu J. C. Leuch's Samml. neuer Abhandlgn. u. Erfindg. in der Eisen-u. Stahlbereit. Mit 5 Holzschn. gr. 8. Nürnberg, 835: Leuchs u. Comp.

Zeitblatt für Gewerbtreibende u. Freunde der Gewerbe. Unter Mitwirkung mehrerer Techniker u. Fabrikanten herausgeg. v. Heinr. Weber. 3r Bd.

Verhandl. des Vereins z. Beförderung des Gewerbsfleisses in Preussen. iv.
Ebend, v. (2) and xii.

7.—*Cannon-founding.*

Meineke, Joh. Ludw. Geo. — Anleit. zum Guss des bronzirten Geschützes. gr. 8. Lemgo, 817. Meyer.

Meyer, Mor.—Erfahrgn. üb. Fabrikation u. Haltbarkeit des eisernen u. bronzenen Geschützes. 2[te]. verm. und theilweise umgearb. Aufl. Mit 3 Kpf.-Taf. gr. 8. Leipzig, (831), 836. Barth.

Ders. in Erdmann's Journal u. Schweiger's Journal für Chemie u. Physik, 1–5.

Müller, Fr. Heinr.—Vers m. Bronce u. gelbem Metall in Anseh. des Gebrauchs desselben, um Kanonen u. Mörser daraus zu giessen. Nebst einer Zeichn. eines dazu gehörigen Schmelzofens, &c. A. d. Dän, v. J. A. Markussen. gr. 8. Copenhagen, 802. Schubothe.

8.—*Fire-arms.*

Struensee, Karl August.—Anfangsgründe v. Artillerie, 1. 8. Seignitz. u. Leipzig, 1788. A very complete work.

Berger, Frz. Xav.—Kurzer Unterricht üb. die Einricht., Conservation, zweckmass. Behandl., u. wirksamste Anwend. des Feuersgewehrs. 8. Wien, 809. Gerold.

Beroaldo, Bianchini de.—Abhandl. üb. die Feuer—u. Seitengewehre; worin die Erzeug, der Zweck, u. der Gebr. aller einzelnen Bestandtheile, dann aller Gattungen kleiner u. Jagdgewehre; mit der Angabe u. Beschreib. ganz neuer Maschinen u. Vorrichtgn., sammt Plänen u. Erzeugeugstabellen anseinandergesetzt ist. 3 Bde. Mit 38 Steint. gr. 4. Wien, 829. Gerold.

Flinte, die, od.—Beschreib. aller Theile des Schiessgewehres, sammt einer Anweis. solches zu putzen u. mit Vorsicht zu behandeln. 8. Fürth, 817. Korn.

Schauplatz, 83 Bd.—Die Geheimnisse der Engl. Gewehrfabrikation u. Büchsenmacherkunst, so wie der Erzeug. der verschied. Eisensorten zu den feinsten Jagdgewehren, anfgedeckt u. erlaüt. v. Will. Greener. Aus. d. Engl. übersetz. v. Chr. Hein Schmidt. 2te sorgfält. revidirte, u. mit einem Anh. des Uebersetzers üb. Anfertig. der Militär-u. Jagdgewehre vermehrte Aufl. Mit 6 Steintf. 8. Ebend, (836), 842.

Glünder, G. W.—Einricht. u. Gebrauch des kleinen Gewehres im ganzen Umfange. gr. 8. Hannover, 829. Hahn.

Infanterie Zündhütchengewehr, das, u. der Nutzen, nebst einer prakt. Theorie des Schiessens zum Unterricht. der Mannschaft, bearbeit. von ein. k. bayer Offizier. 16. Passau, 842. Pustet.

Prechtl's Encyclopädie, 6 vol.

Roux, Joh. Wilh.—Der Gewehrkenner, od theoret-prakt. Anweis. die Jagdgewehre, vorzüglich die Büchsen zu vervollkommen, ihre Fehler zu entdecken u. mit leichter Mühe zu verbessern. 8. Leipzig, 822, Steinacker.

Schild, Günth.—Deutl. Anweis. üb. den richtigen u. zweckmässigen Gebrauch der Jagdflinte. 8. Nordhausen, 824. (Leipzig, Dörffling.)

Spönemann, A.—Hülfbuch f. jeden Gewehrbesitzer. Für jeden Freund des Schiessens und der Jagd. Mit Abbildgn. (auf 1 Bl.). 2te Aufl. 8. Quedlinburg (839), 840, Basse.

Thon, Chr. F.—Schiesskunst, od. vollständ. Anweis. zum Schiessen, mit der Büchse Flinte u. mit Pistolen, sowohl auf dem Schützenhofe, als auf der Jagd u. im Felddienste. Ein nothwend. Handb. für Jäger, Schützen, u. Offiziere, &c. 2te Aufl. 8. Ilmenau, (822), 824. (Weimar), Voigt.

Unterricht üb. den Bau u. Gebrauch des Gewehrs. u. der Büchse. Von C. von M. 8. Breslau, 813. (W. G. Korn.)

Versuch üb. du Gewehrfabriken, die Schiesskunst, u. das Jagdwesen. Aus. d. Engl., nach der 2ten Ausg. Mit Anmerkgn. v. Gbh. Er. Lp. Timaüs. gr. 8. Leipzig, 790. (Reineke.)

Wolf, Ferd.—Die Verfertig der Handfeuerwaffen, nebst einer geschichtl. Darstell. ihrer Einricht. von der Entsteh. bis auf die neuste Zeit. Mit 18 Kpftf (in qu. gr. Fol.). gr. 8. Karlsruhe, 832. Groos.

Wolf, F.—Vollständ. Berichterstatt. üb. die im J. 1832 u. 1833 geführten ausgedehnten Versuche. Mit Militar-Percussions-Gewehren. (Mit 2 Steintf.) 8. Carlsruhe, 833. (Nöldeke.)

9.—*Rifled Guns.*

Grasshoff, F.B.G.—Kurzer, auf prakt. Erfahr. gegründ. Unterricht für Büchsenschützen üb. die erforderliche Beschaffenheit einer guten Pürsch-Büchse od. sogenannten Stutzen. N. Ausg. 8. Breslau, (803), 813. W. G. Korn.

Hauchekornè, Fr. Wilh.—Lehrbuch der Technologie, od. Beschreib. der Künste u. Gewerbe. Mit 5 Kpf. gr. 8. Leipzig, 816. Brockhaus.

Meister, F. L.—Theorie der Zerleg. des Stutzers, des Distanzenschätzens u. Schiessens. Den schweiz. Scharfschützen gewidmet. 16. Bern, 838. Walthard.

Schauplatz, 131 Bd.—Beiträge zur Kenntniss der Büchsenmacherkunst u. zur richtigen Beurtheil. der Schiessgewehre. Von J. Schmidt. Mit 10 Taf. Abbild. 8. Ebend, 843.

Schmidt, P. W.—Die Jäger-u. Schützenbüchse od. die spiralförmig gezogene Büchse im Allgemeinen, deren Einricht., Behandl. u. Gebrauch nach dem neuesten Standpunkte der Entfindgn. u. Wissenchaften. Mit 2 Kpfl. gr. 8. Halle, 827. (Mühlmann.)

10.—*Percussion and Needle Muskets.*

Köhnemann, R. H. B.—Regeln üb. der Behandl. des Percussions-Gewehrs. Mit 2 Abbildgn. des Gewehrs. in Steindruck. gr. 12. Oldenburg, 841. Schulze.

Perkussions-Infanterie-Gewehr, das Preusische, eine, die Zusammensetz. Behandl. Trefflichkeit, den Gebrauch u. den Mechanismus umfassende Handschrift. Dem Soldaten zur Selbstbelehr., dem Vorgesetzten zum Leitfaden beim Unterricht seiner Untergebenen von einem erfahrenen Kamaraden. 8. Minden, 842. Essmann.

Freiburg in Verhandl. zu Beförderung des Gewerbfleisses in Preussen. x.

The preceding list is not to be understood as aiming at completeness: it merely embraces such works as have come under my notice: I omit all French works, as complete catalogues exist of their magnificent military literature. A very considerable body of ordnance and pyrotechnic literature exists in Italian and Spanish, of which almost nothing is known in England. The works in the former language are chiefly ancient, and historically important; but the scientific treatment of artillery and gunnery, by recent authors, in Spain, appears to be in a much more advanced state, than the isolation of their meagre literature has enabled us to appreciate.

It is an unhappy indication of our own neglect and ignorance, that a few months ago (perhaps even yet) many of the most important standard works, historical and otherwise, in Continental languages, were unknown to us, and not to be found in any of our great libraries. General Marion's great work on the History of Artillery was not in the British Museum, nor in any other public library in England or Ireland to which I had access; the few books on the subject in the Library of Trinity College, Dublin, quite accord with the venerable title they are classed under, "De Machinis Bellicis;" and almost no modern foreign books on artillery exist in the Library of the United Service Institution, London, nor in any of the Royal Engineer libraries that I am acquainted with.

How desirable it would seem to form at Woolwich a complete historical and scientific military library, at the public charge, and collect there all that has been written, in every language, on the subject of Arms, in the widest sense (not, perhaps, excluding the military art as a whole, strategics, &c.), and not only give professional access to it, but permit every man, known to be really interested and engaged, in the advancement of any branch of the subject, the freest possible admission. The nucleus of such a collection exists already in the Library of the Royal Military Academy; and, while the position itself is good, perhaps no officer in the Service could be found so admirably suited, by learning, taste, general ability, and desire of progress, to direct its formation and control its use, as my friend, Colonel Portlock, R. E., the Commandant. I hope he will pardon my thus venturing, without his sanction or knowledge, to connect his name with the idea.